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CHARACTERISTICS OF TRAFFIC FLOW ON FREEWAYS[a]

Adolph D. May, Jr.[1]

SYNOPSIS

Traffic flow characteristics were studied on two high density controlled access facilities in Detroit, Michigan. Average speeds and volumes were recorded on a per minute, per lane basis. The paper is presented in four parts: traffic volume characteristics, speed characteristics, vehicle headway characteristics, and relationships of fundamental characteristics.

I. INTRODUCTION

Controlled access facilities are the most expensive highway facilities that are built. This additional investment is made in order to preserve the geometric features of the highway and thereby insure its permanence not only structurally but geometrically. Essentially controlled access facilities provide geometric design features which eliminate or greatly minimize intersectional, medial, and marginal interferences.

This paper discusses a fourth interference or friction which exists on high density controlled access facilities. This interference, internal friction, is that friction which is created between vehicles moving in the same direction. Under low density conditions, internal friction is slight and is not an appreciable problem. However, under high density conditions internal friction may become so great as to completely stagnate the total traffic movement on our best designed and most expensive facilities. Unfortunately, this stagnation occurs when there is the greatest need for the most efficient operation.

As a result of the inefficient use of controlled access facilities during high density conditions, and the uneconomical operation and inconvenience to the

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a. Presented at the February 1959 ASCE Convention in Los Angeles, Calif.

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motorist, research studies have been conducted in several states on this very important problem.[1,2,3,4] This paper is a progress report of one such study.

The Highway Traffic Safety Center of Michigan State University is currently embarked on a research study of the fundamental characteristics of traffic flow. This project is being sponsored by the Michigan State Highway Department and the United States Department of Commerce Bureau of Public Roads, in cooperation with the City of Detroit and Wayne County.

II. Scope and Purpose

The scope of this paper is limited to the presentation of some of the results of the research project "Fundamental Characteristics of Traffic Flow" currently being conducted at the Highway Traffic Safety Center. Nine study locations in urban areas have been selected and represent facilities with various combinations of marginal and medial friction. The design of experiment is based on the four friction concept[5,6] which, in essence, classifies road and traffic characteristics which resist traffic flow into four types of friction—internal, medial, marginal, and intersectional. Internal friction, defined as that friction which exists between vehicles moving in the same direction, is present at each of the nine study locations because of the high volume of traffic at these locations. Intersectional friction, that friction which exists between

DESIGN OF EXPERIMENT

MEDIAN FRICTION → / MARGINAL FRICTION ↓	NONE (WIDE MEDIAN)	MODERATE (NARROW MEDIAN)	HEAVY (NO MEDIAN)
NONE (ACCESS CONTROL)	1	2	3
MODERATE (NO PARKING)	4	5	6
HEAVY (PARKING)	7	8	9

NUMERALS REFER TO CELL NUMBERS

Fig. 1

vehicles moving at right angles to one another, was eliminated by selecting study locations away from the influence of intersectional movement. Various degrees of medial and marginal friction were studied and are illustrated in Fig. 1. Three levels of medial friction (no median, narrow median, wide median) and three levels of marginal friction (heavy parking, no parking, access control) are included in the design of experiment, resulting in a three by three classification table. One study location was selected for each classification or cell. Each study location had the following similar characteristics: level and tangent roadways, urban environment, heavy traffic volumes, absence of intersectional friction, continuity of amount and type of medial and marginal friction some distance upstream and downstream from study location, minimum driver visibility of survey equipment, multi-laned facilities, and minimum influence due to changing weather conditions.

This paper is limited to the results thus far obtained from the two study locations on high density controlled access facilities. One location was on the Ford Expressway (cell 1) while the other location was on the Davison Expressway (cell 2).

The specific characteristics and phenomena of traffic operations obtained on the two controlled access facilities that are included in the presentation are:

1. Traffic Volume Characteristics
2. Speed Characteristics
3. Vehicular Headway Characteristics
4. Interrelationship of the Fundamental Characteristics of Traffic Flow

Fig. 2

III. Survey Narrative

A. Description of Study Locations

The Detroit Expressway system consists of three expressways: the Davison, Ford, and Lodge. A map showing the location of the expressway system, the major street network, and study locations is shown in Fig. 2.

The Davison Expressway is the oldest expressway in the Detroit area having been constructed in 1941. The Davison is an east-west expressway, approximately 1.5 miles in length, and located five miles north of the downtown area. The only entrances and exits to this expressway are at the terminal points. A tabulation of the geometric design features of the Davison, as well as the Ford and Lodge, are presented in Fig. 3. A study location was selected on the Davison so as to obtain traffic characteristics for an expressway having a narrow median and representative of the older type expressways. The exact location (Fig. 2) was thirty feet west of the Woodward Avenue overpass structure and data were obtained for westbound traffic.

The Ford is an east-west expressway approximately eight miles in length, and located two miles north of the downtown area (Fig. 2). The geometric design features of the expressway are typical of the more recently built expressways and these features are summarized in Fig. 3. The study location on the Ford Expressway (Fig. 2) was at the Lonyo Street overpass and data were obtained for eastbound traffic.

The third expressway of the Detroit system is the Lodge Expressway. This expressway extends northward from the downtown area and is approximately eight miles in length (Fig. 2). The geometric design features are presented

Geometric Design Features of the
Davison, Ford, and Lodge Expressways

Design Feature	Davison	Ford & Lodge
No. of Lanes (each direction)	3	3*
Width of Lanes	11 - 11 - 11	12 - 12 - 12
Type of Edge	Curb & Gutter	Curb & Gutter
Shoulder (outer)	None	8'-paved
Shoulder (inner)	None	None
Median Type	Raised with barrier	Raised with barrier
Median Width	6'	12'
Pavement Type & Condition	Concrete, Good	Concrete, Excellent
Speed Limit	45	40 - 55

*The Lodge Expressway has a short section of four lanes in each direction north of the Ford Expressway.

Fig. 3

in Fig. 3. A study location was not selected on the Lodge Expressway since its geometric design features were similar to the Ford Expressway, and traffic volumes are generally lighter on the Lodge.

B. Data Processing

The processing of the data at the two locations on the Detroit Expressway system consisted of (1) detecting traffic volume, speed, and headway information; (2) transmitting these characteristics to a central office; (3) summarizing these characteristics on graphical and digital recorders; and (4) analyzing the data manually and mechanically.

A radar speed detector and volume detector were installed for each lane at each site to detect speeds of each vehicle, the time headway between each pair of vehicles, and the volume of traffic for any period of time. The above mentioned variables were measured continuously for a period of seven days. The volume detectors were centered over each lane and placed approximately sixteen feet over the pavement. An external sensitivity control was placed in an accessible control box in order to adjust the sensitivity of each volume detector.

The installation of the speed detectors on the Ford Expressway site differed from the Davison Expressway site. In both cases the speed detector for the lane next to the median was placed in the median and the speed detector for the outer lane was placed on the shoulder. On the Ford Expressway the speed of vehicles in the middle lane was obtained by measuring the speeds of vehicles in the middle and outer lanes combined, and subtracting the speed of vehicles in lane 3. The detector for speeds for the combined lanes was placed on the shoulder. At the site on the Davison Expressway speeds of individual vehicles were obtained directly by placing the speed detector in the center of

Fig. 4. Radar isntallation—Eastbound Edsel Ford Expressway at Lonyo Overpass

the lane and sixteen feet over the pavement. The speed detector was tilted to approximately forty-five degrees with the pavement, and was calibrated to compensate for the cosine angle error. This arrangement has been used at all other field sites since the recorded speeds are easier to analyze and are free from echoes of downstream large vehicles. Photographs of the installed equipment at the two field sites are shown in Figs. 4 and 5. (The photography shown in Fig. 5 was taken before installation of the speed meter over lane 2.)

The transmission of speed, volume, and headway characteristics from the two study locations were accomplished in different manners. The transmission of the detected characteristics on the Ford Expressway was provided by using Bell Telephone wires to a central office approximately one and one-half miles away from the study location. Although this method was satisfactory, it was deemed advisable on the Davison and at other sites to locate the central office at the field site in order to facilitate calibration of equipment and for checking the accuracy of the measurements. A seventeen foot trailer was used as a central office at the field site.

The measured characteristics were received at the central office and connected to a master switchboard. From the switchboard the impulses were channeled to their respective recorders. Photographs of the switchboard and recorders are shown in Fig. 6. The volume impulses were passed through a relay which permitted two recordings of the same impulse—one for headway and the other for volume. Headway was recorded on a twenty pen recorder which had four pens operating—one for each lane and the fourth pen with manual control for daily volume checks. The chart speed of the recorder was six inches per minute which permitted obtaining headways to the nearest quarter of a second. The volume impulses for volume were connected to either a volume-density computer and then a one minute plotting graphical

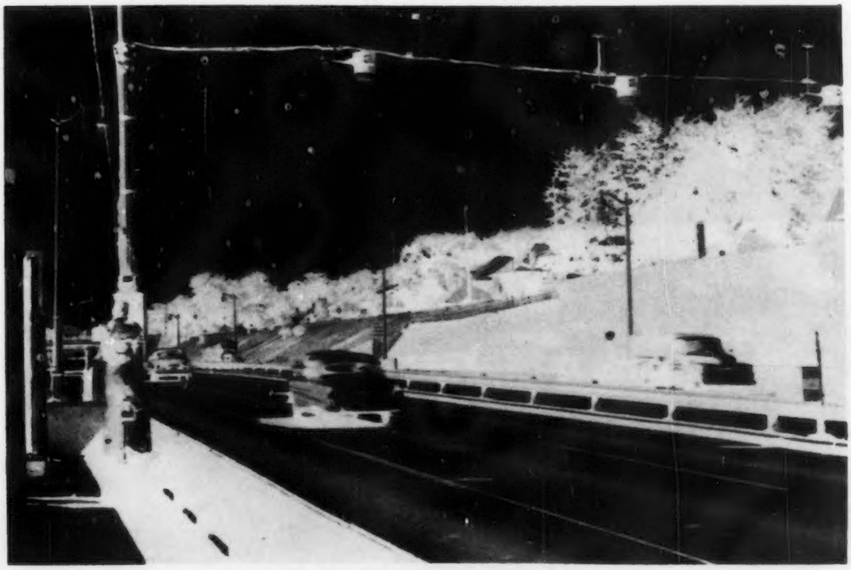

Fig. 5

recorder or the impulses were transmitted to a one minute digital recorder. The headway tapes could be utilized for determining volume information for periods less than one minute. The speed impulses were routed directly to speed recorders which were operating at chart speeds of one and one half inches per minute.

A volume and speed check was made each morning and afternoon for each lane when the station was in operation. These checks indicated that the minute

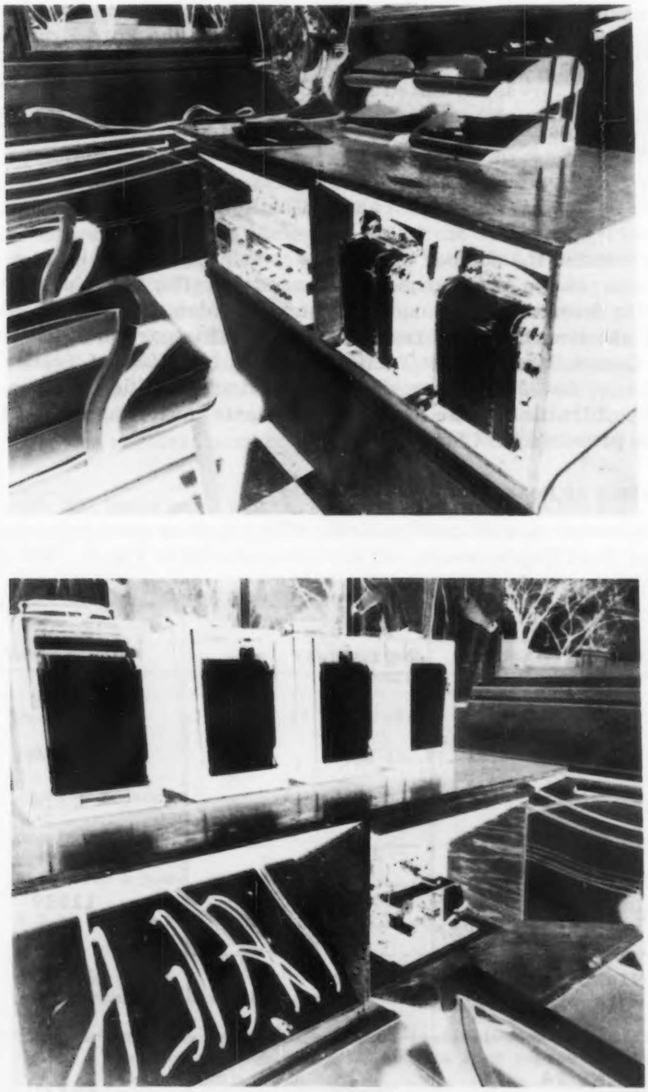

Fig. 6

volumes were normally accurate to within $\pm$ 0.7% and the minute average speeds were normally accurate to within $\pm$ 1.5 miles per hour. If the minute volumes were in error in excess of $\pm$ 3% or the minute average speeds were in error in excess of $\pm$ 2.0 miles per hour, the detectors were recalibrated until the measured characteristics met the specified accuracy requirements.

The greatest difficulty encountered in this project was the summarization and analyses of data for this operation was tedious and extremely time consuming. The speed and volume impulses were analyzed for each vehicle by lane, and summarized in one minute, fifteen minute, and one hour intervals for a typical week-day twenty-four hour period. On the Ford Expressway, speed and volume impulses of 49,731 vehicles were recorded and analyzed. On the Davison Expressway speed and volume impulses of 26,699 vehicles were recorded and analyzed. Time headways were analyzed for selected time periods only on the two controlled access facilities.

IV. Traffic Volume Characteristics

Traffic volume, the number of vehicles passing a given point in a specified period of time, is the most frequently measured traffic flow characteristic. In addition to determining the numerical traffic volume, it is of considerable interest to study variations in traffic volumes. This portion of the report includes (1) Comparison of Peak Traffic Volumes; (2) Effect of Traffic Volume on Lane Usage; and (3) Distribution of Daily Minute Traffic Volumes. The relationship of traffic volume to other fundamental characteristics of traffic flow will be presented in Chapter VII.

A. Comparison of Peak Traffic Volumes

The factors for various peak period traffic volumes were computed for the Davison and Ford Expressways and are summarized in Fig. 7. The peak period volumes are shown in the table below.

Peak Period	Davison Expressway	Ford Expressway
1 Minute	63	115
5 Minute	283	496
15 Minute	775	1424
1 Hour	2763	5268
Daytime (6 AM to 6 PM)	7887	11989
Night time (6 PM to 6 AM)	18812	37742
Total 24 Hour Volume	26699	49731

The results obtained from the two controlled access facilities are almost identical. This similarity is even more important to observe considering the differences in twenty-four hour volumes, design features, amounts of truck traffic, and type of trips served. The figures in parentheses in the table are for the Ford Expressway and the table is arranged so that entering with one, five, fifteen, hour, or twenty-four hour peak traffic volume, the volume for the other peak periods can be estimated.

B. Effect of Traffic Volume on Lane Usage

Considerable interest has been shown in determining the effect that truck traffic and the presence of off- and on-ramps have had on the traffic usage of the outer lane (lane 3)* particularly during high density conditions. Interest also has been indicated as to what proportion of the traffic use the inner lane (lane 1) is due to the current controversy of off- and on-ramps on the median side. The study locations were selected a considerable distance from off- and on-ramps and consequently the lane usage analysis indicates the volume distribution between lanes with little influence from off- and on-ramps.

The lane usage on the two controlled access facilities under various volume conditions are shown in Fig. 8. The vertical scales are number of vehicles per minute per lane while the horizontal scales are total minute volumes for the three lanes. The diagonal lines sloping up to the right indicate the per cent of lane usage. On the Davison Expressway from a total minute volume of 1 to 25 vehicles, lane 2 carries the greatest number of vehicles, followed by lane 1 and then lane 3. For total minute volumes in excess of 25 vehicles, lane 1 carries the greatest number of vehicles, followed by lane 2 and then

*In this study the lanes were numbered from the median to the right. This method of numbering the lanes is the reverse with that used in the capacity manual.

Comparison of Peak Traffic Volumes

	Five Minute	Fifteen Minute	One Hour	Twenty-Four Hour
One Minute	22.3 (23.2)*	8.1 (8.1)	2.3 (2.2)	0.24 (0.23)
Five Minute	___	36.5 (34.8)	10.2 (9.4)	1.1 (1.0)
Fifteen Minute	___	___	28.0 (27.0)	2.4 (2.4)
One Hour	___	___	___	10.4 (10.6)
6 a.m. to 6 p.m.	___	___	___	70.5 (75.9)
6 p.m. to 6 a.m.	___	___	___	29.5 (24.1)

*The numbers in parentheses refer to Ford Expressway

Example - The one minute peak volume (115) divided by the five minute peak volume (496) on the Ford Expressway is equal to 23.2 per cent.

Fig. 7

lane 3. As an example, with a total volume of fifty vehicles, the expected distribution of traffic volumes between lanes 1, 2, and 3 would be 21, 18, and 11 vehicles respectively.

The volume distribution between lanes is somewhat different on the Ford Expressway. Between total minute volumes of 1 to 30, lane 2 carries the grestest number of vehicles, followed by lane 3 and then lane 1. As the total minute volume exceeds 30 but remains less than 80, lane 2 still carries the greatest number of vehicles but lane 1 then carries more than lane 3. For minute volumes greater than 80, lane 1 and lane 2 carry equal volumes (40%) while lane 3 carries only about half as much.

In comparing the lane usage on the two controlled access facilities, lane 3 generally carries the smallest amount of the volume, particularly at the higher volume ranges when the need for capacity is the greatest. In fact, on both facilities lane 3 carries only one-fifth of the volume. An important difference between the two facilities is that lane 3 is used more and lane 1 is used less on the Ford Expressway than on the Davison. This is at least partly due to the higher per cent of trucks on the Ford Expressway.

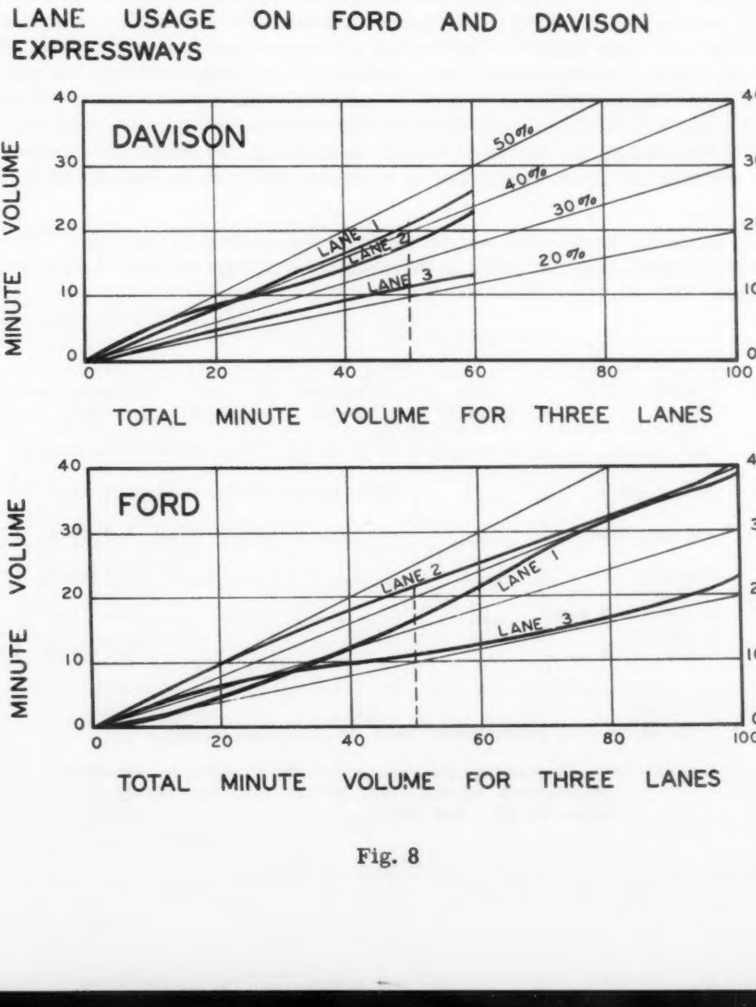

Fig. 8

The twenty-four hour distribution of the traffic volume between lanes 1, 2, and 3 on the Davison Expressway was 39.0%, 40.8%, and 20.2%; while on the Ford Expressway it was 31.8%, 43.1%, and 25.1%.

C. Distribution of Daily Minute Traffic Volumes

Since the traffic volume for each minute of the selected twenty-four hour period of each controlled access facility was recorded, it was possible to determine the range and distribution of the minute volumes. The minute volume range on the Davison Expressway was 0 to 63 vehicles while on the Ford Expressway the volume range was 0 to 115 vehicles. Since twenty-four hour volumes are frequently obtained while minute volumes are not, it was felt desirable to attempt to express the minute volume distribution in terms of the twenty-four hour volume. The procedure adopted was to relate the twenty-four hour percentile minute volume in terms of a ratio of the minute volume of the indicated percentile to the twenty-four hour average minute volume. This relationship is presented graphically in Fig. 9 and the results from the data obtained on the two controlled access facilities are indicated. The two curves are almost identical and present possible broader application to other controlled access facilities considering the extreme differences in these two facilities. As an example, assume that the twenty-four hour ninety percentile minute volume on the Davison Expressway is desired (that minute volume which is exceeded ten per cent of the minutes during the day and is greater than the remaining ninety per cent of the minutes). Entering the graph with the ninety percentile volume, the ratio of the desired minute volume to the twenty-four hour average minute volume is 1.89. The twenty-four hour volume was 26,699 vehicles and the average minute volume was 18.5 vehicles. The desired minute volume is 1.89 times the 18.5 or 35 vehicles per minute. In this manner any desired minute traffic volume could be estimated.

METHOD OF ESTIMATING VARIOUS PERCENTILE MINUTE VOLUMES

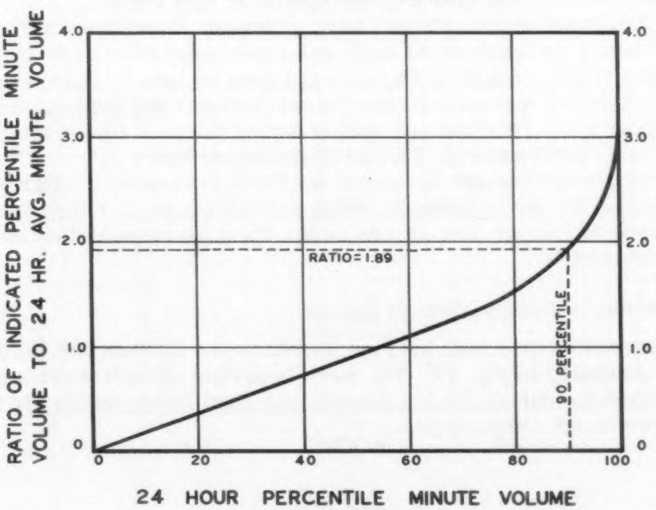

Fig. 9

V. Speed Characteristics

Another important fundamental characteristic of traffic flow is speed. Speed characteristics which will be presented in this chapter are (1) Variation of Average Speeds by Time of Day and (2) Distribution of Minute Average Speeds. The relationship of average speed to other flow characteristics will be presented in Chapter VII.

A. Variation of Average Speeds by Time of Day

The individual speed of each vehicle in each lane was determined on both controlled access facilities for a twenty-four hour period. The individual speeds were averaged for one minute and fifteen minute intervals by lane. Since the number of observations in the one minute period intervals were relatively small, average lane speeds by fifteen minute intervals were computed and graphically presented in Figs. 10 and 11 for the Davison and Ford Expressways.

The average speed on the Davison Expressway for the twenty-four hour period for lanes 1, 2, and 3 was 47.7, 48.2 and 46.2 miles per hour. The average speed for all lanes for the twenty-four hour period was 47.6 miles per hour. The average speeds during the early morning hours vary considerably due to the relatively small number of speed observations during the fifteen minute intervals. The average speeds in lanes 1 and 2 are generally greater than speeds in lane 3, and vary from 45 to 50 miles per hour. The average speed in lane 3 varies from 43 to 50 miles per hour. The peak hour occurs from 4:30 to 5:30 p.m. but speed does not seem to be affected.

The average speeds for the twenty-four hour period on the Ford Expressway for lanes 1, 2, and 3 were 49.5, 46.0 and 41.0 miles per hour. The average speed for all lanes for the twenty-four hour period for all three lanes was 45.5 miles per hour. Again there is considerable variation in the fifteen minute average lane speeds during the early morning hours due to the small number of observations. The average speeds in lane 1 normally are the highest, while average speeds in lane 3 are the lowest. The fifteen minute average speed for lane 1 varies from 46 to 51 miles per hour; from 44 to 48 miles per hour in lane 2; and from 40 to 45 miles per hour in lane 3. It is of special interest to observe that average speeds are considerably reduced during the morning peak hour. The average speeds during the peak fifteen minute period for lanes 1, 2, and 3 were 40, 39, and 32 miles per hour.

The average lane speeds on the two facilities were quite similar with the lane speeds on the Davison usually being slightly greater. There was a greater difference in average lane speeds on the Ford Expressway than on the Davison Expressway.

B. Distribution of Minute Average Speeds

The distribution of minute average speeds on the Davison and Ford Expressways are presented in Fig. 12. The more important characteristics of the speed distribution curves for the Davison and Ford Expressways are presented in the tables on the following pages.

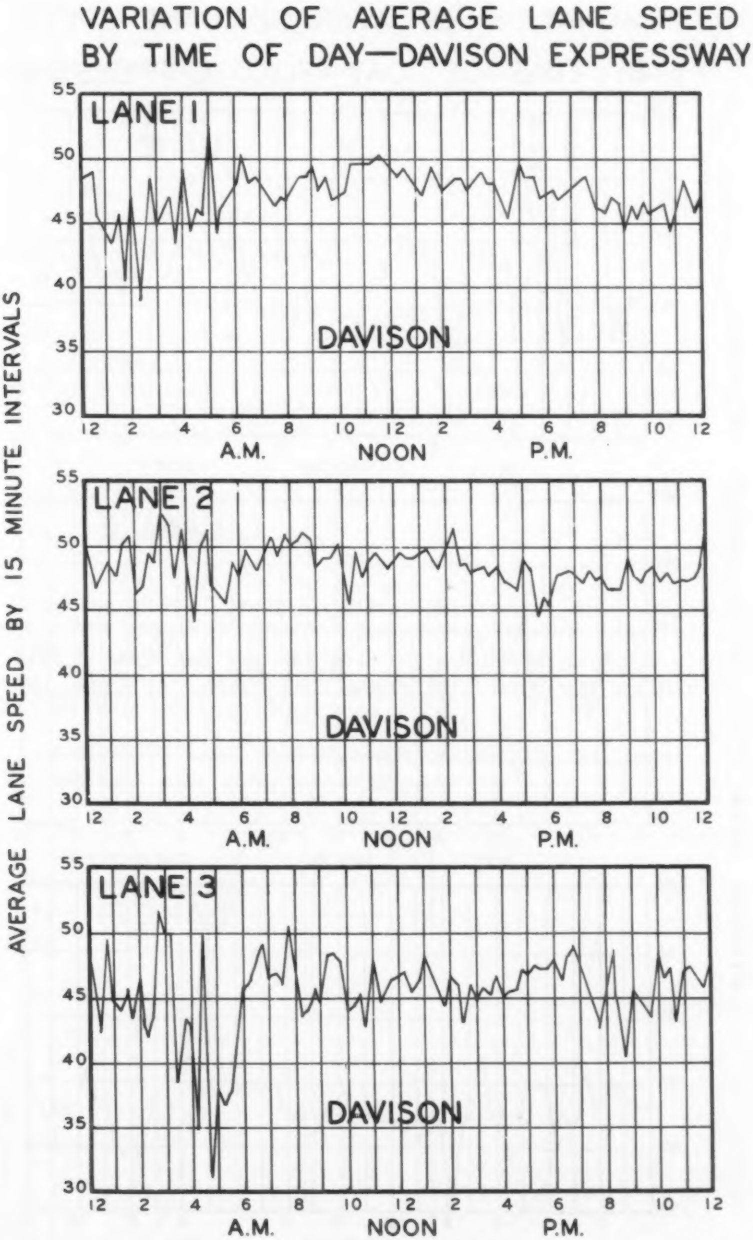
VARIATION OF AVERAGE LANE SPEED BY TIME OF DAY—DAVISON EXPRESSWAY
AVERAGE LANE SPEED BY 15 MINUTE INTERVALS
LANE 1
LANE 2
LANE 3
DAVISON
DAVISON
DAVISON
55
50
45
40
35
30
12 2 4 6 8 10 12 2 4 6 8 10 12
A.M.
NOON
P.M.

Fig. 10

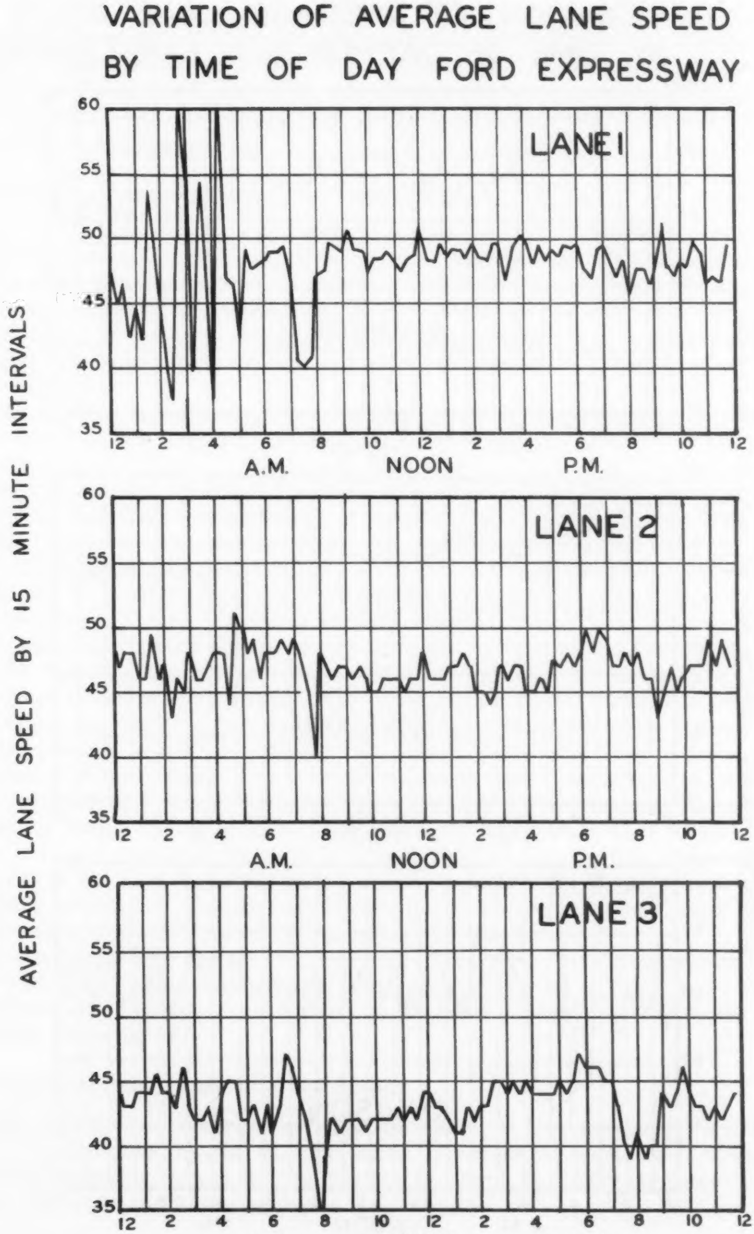
VARIATION OF AVERAGE LANE SPEED
BY TIME OF DAY FORD EXPRESSWAY
AVERAGE LANE SPEED BY 15 MINUTE INTERVALS
LANE 1
LANE 2
LANE 3
60
55
50
45
40
35
12 2 4 6 8 10 12 2 4 6 8 10 12
A.M.
NOON
P.M.

Fig. 11

Davison Expressway

Speed Characteristic	Lane 1	Lane 2	Lane 3
15 Percentile	45	45	42
50 Percentile	48	48	46
Average Speed	48	48	46
85 Percentile	51	52	50
15-85 Percentile Range	6	7	8

Ford Expressway

Speed Characteristics	Lane 1	Lane 2	Lane 3
15 Percentile	43	43	39
50 Percentile	47	46	41
Average Speed	49	46	41
85 Percentile	51	49	44
15-85 Percentile Range	8	6	5

With the exception of lane 3 on the Ford Expressway, the distribution of average minute speeds by lane are quite similar. The 15 percentiles vary from 42 to 45 miles per hour and the 50 percentiles vary from 46 to 48 miles per hour. The 85 percentiles vary from 49 to 52 and the 15 to 85 percentile ranges vary from 6 to 8 miles per hour.

DISTRIBUTION OF MINUTE AVERAGE SPEEDS ON THE DAVISON AND FORD EXPRESSWAYS

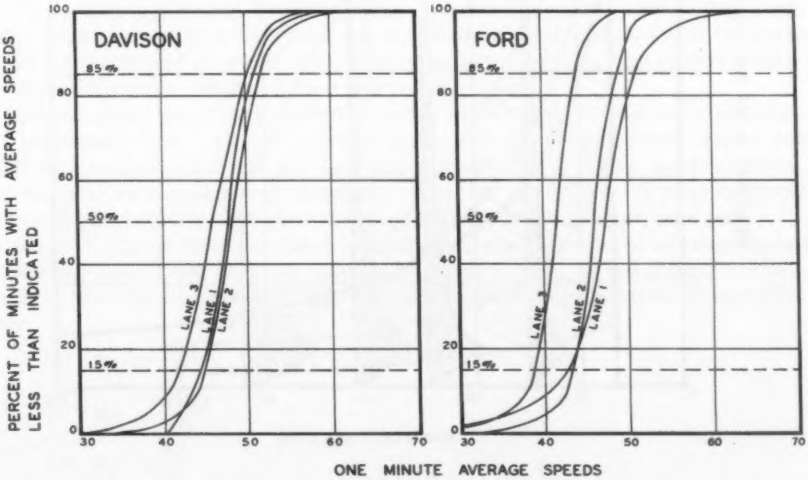

Fig. 12

VI. Vehicular Headway Characteristics

The headway or time interval between vehicles is one of the most interesting fundamental characteristics of traffic flow. It is relatively simple to compute the average headway for a given time interval since it is equivalent to the number of seconds in the time interval divided by the traffic volume during the selected time interval (assuming the desired units of headway are seconds). As an example, if a lane of a highway has a volume of 25 vehicles in one minute, then the average time headway is 60 divided by 25 or 2.4 seconds.

However, in order to better understand the phenomena of traffic flow, it is of value to know how headways are distributed under various traffic volumes. An attempt will be made in this paper to graphically present the analyzed headway information in a rather unique manner in order to develop some rather important relationships. This presentation appears in Fig. 13 and only data from lane 1 of the Ford Expressway are illustrated. The vertical scale is time headway in seconds while the primary horizontal scale is minute lane volumes. The distribution of headways for volume ranges of 0 to 9, 10 to 19, 20 to 29, 30 to 39, and 40 to 49 vehicles per minute for lane 1 were determined and the distributions plotted for each volume range. The 15 percentile, 50 percentile (median), 75 percentile, 85 percentile, and 100 percentile were determined for each of the five distributions and the five solid light-weight lines

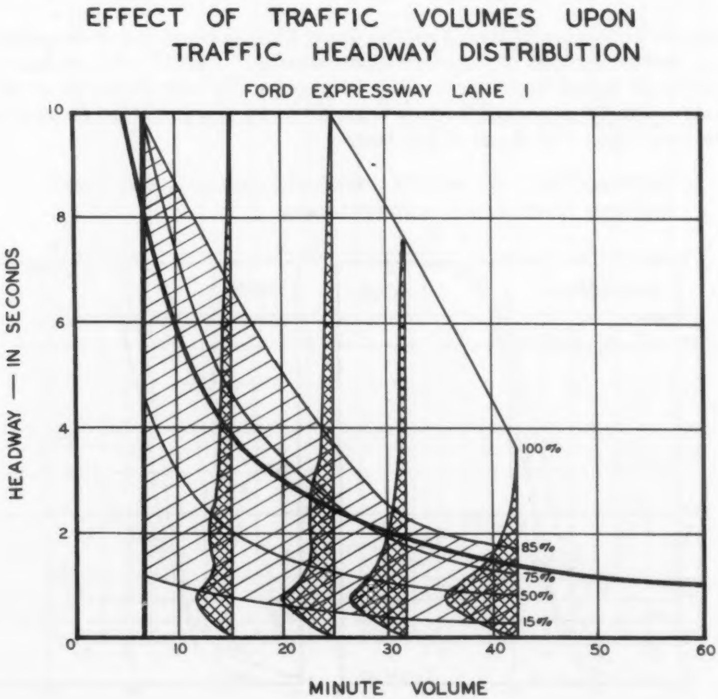

Fig. 13

sloping down and to the right connect these various percentiles. The single solid heavy-weight line sloping down and to the right represents the relationship between average minute headway and minute volume.

The headway distribution has the greatest spread at the lower volume ranges and becomes narrower at the higher volume ranges. It is rather unique that the mode for each of the five distributions was the 0.5 to 1.0 second headway group. The mode becomes more pronounced at the higher volume ranges. An interesting phenomena exists between the average headway curve, 75 percentile curve, and the 50 percentile curve. The 75 percentile curve is almost identical to the average headway curve while the values on the 50 percentile curve are approximately one-half of the corresponding average headway values. Additional information needs to be obtained for other lanes and for other facilities and further statistical analyses performed. However, from the limited data analyzed, it would seem that by computing the average headway some statements of the headway distribution can be made. For example, if the minute volume is determined and found to be 25 vehicles, the average headway is 2.4 seconds. Approximately one-half of the vehicles (12) at this volume are traveling with headways less than 1.2 seconds, one-fourth (6 vehicles) are traveling with headways of 1.2 to 2.5 seconds, and the remaining one-fourth (6 vehicles) are traveling at headways greater than 2.5 seconds.

VII. Interrelationship of the Fundamental Characteristics of Traffic Flow

The fundamental characteristics of traffic flow have been discussed as separate phenomena in the three previous chapters. This chapter will attempt to illustrate how these characteristics—volume, speed, and headway—are interrelated. A fourth characteristic, traffic density, will be included in this discussion. Traffic density, as the name implies, is a measure of the density of traffic and can be expressed as the number of vehicles occupying a one mile section of highway. In this discussion, traffic density will be presented on a per lane basis. Density can be obtained directly by photographic techniques or by input-output volume counts. Another method, used in this study, is to compute density mathematically by dividing the traffic volume by average speed. Volume and average speeds were determined on a per minute basis, and densities were computed on a per minute basis.

Mathematical equations needed in order to develop the interrelationships are (a) density (vehicles per mile) as a function of average speed (miles per hour) and volume (vehicles per lane per minute); (b) distance headway (feet per vehicle) as a reciprocal of density (vehicles per mile); (c) time headway (seconds per vehicle) as a reciprocal of volume (vehicles per lane per minute); (d) travel time (minutes per mile) as a reciprocal of average speed (miles per hour); and (e) time loss (minutes per mile) as the difference between actual travel time per mile and an assumed standard travel time per mile.

(a) $D = \frac{600}{V}$

(b) $H_d = \frac{5280}{D}$

(c) $H_t = \frac{60}{Q}$

(d) $T = \frac{60}{V}$

(e) $T_L = T - 1.0 = \frac{60}{V} - 1.0$

The above equations were used to construct the graphs of Figs. 14 and 15. The data obtained for each of the three lanes on the Davison Expressway are shown in Fig. 14, while similar characteristics for the three lanes on the Ford Expressway were plotted on Fig. 15.

The left vertical scale is minute volume by lanes while the lower horizontal scale is density. The right vertical scale is the reciprocal of volume which is time headway and the upper horizontal scale is the reciprocal of density which is distance headway. The slope of the family of straight lines extending from the origin and projecting up and to the right represent various speeds since the slope of the lines are equivalent of volume divided by density. The straight lines having the steeper slopes indicate the higher speeds. The half circle curve denotes vehicular time loss per mile of travel using 60 miles per hour or one minute per mile as the standard travel time. As an example, at a speed of 20 miles per hour the travel time per mile is three minutes and represents a time loss of 2.0 minutes per mile.

The fundamental relationships of the traffic characteristics on the Davison Expressway are presented in Fig. 14 for each lane. All characteristics were computed on a per minute basis and each minute of the selected twenty-four hour period was included in this presentation. Unfortunately, the maximum rate of flow was never reached where an increase in density resulted in a reduction in rate of flow. The highest density computed was 35 vehicles per mile. The first impressions obtained from the graph are that all three lanes are quite similar and the curves are almost straight lines passing through the

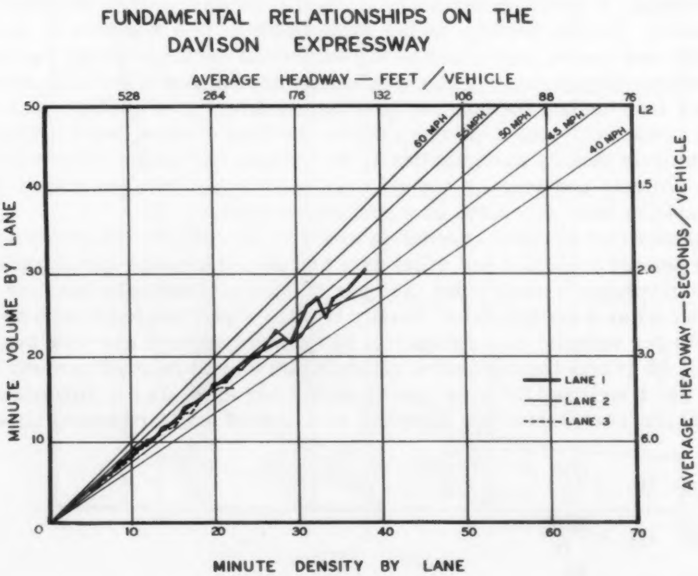

Fig. 14

origin and almost identical to the sloping straight line representing a constant speed of 50 miles per hour.

The fundamental relationships of the traffic characteristics on the Ford Expressway are presented in Fig. 15 for each lane. Similar to the Davison Expressway data, all characteristics were computed on a per minute basis and each minute of the selected twenty-four hour period is included. The curves representing the three lanes are similar in the 0 to 15 density range to the sloping straight line representing 50 miles per hour. In the density range from 15 to 60 the curves for lanes 1 and 2 continue to be extended up and to the right but with a continuing decrease in the slope of curve. At about a density of 60, the slopes are zero. The curve for lane 3 began to flatten out at a lower volume, and reaches its maximum volume (31 vehicles per minute) at a density of 60 to 70. The maximum rate of flow is reached for lanes 1, 2, and 3 at speeds of 37, 39, and 27 miles per hour. The curve for lane 3 did not have a negative slope or any observations at densities greater than the density when the volume is maximum. The curves for lanes 1 and 2 did have negative slopes from densities of 60 to 65 up to densities of 100. At a density of 100, the volume was 23 vehicles per minute, and the speed was 14 miles per hour.

The curves representing the three lanes on the Davison Expressway are quite similar to the curves denoting lanes 1 and 2 of the Ford Expressway. This comparison is limited, however, to observations of densities less than 35. Lane 3 of the Ford Expressway has a flatter slope (lower speed) than any other lane on either of the facilities.

The graphical presentation of the traffic characteristics obtained for the two controlled access facilities are in some respects similar to what might be expected. One limit of the curves is at the point of zero volume and zero density and the other limit occurs at a zero volume but a maximum density

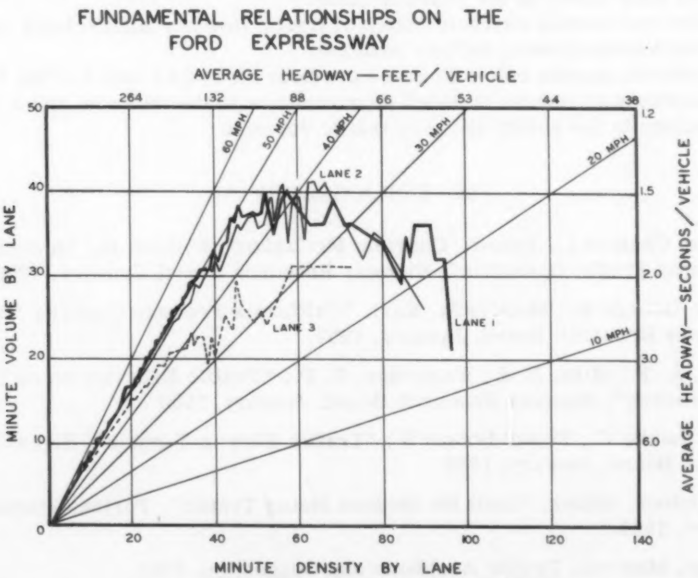

Fig. 15

slightly in excess of 200 vehicles per mile. The data do appear to verify these two limits. On the other hand, there are some unexpected results. The most important difference is that maximum volume occurred at speeds of almost 40 miles per hour rather than 30 to 35 miles per hour for lanes 1 and 2. When the speeds on these two lanes were reduced below 40 miles per hour due to internal friction, not only was there an inconvenience to each motorist but also the facility was losing the opportunity of carrying its maximum traffic load.

VIII. SUMMARY

The more important findings pertaining to the traffic characteristics of the two controlled access facilities are summarized below.

1. The ratio of various peak traffic volumes for different intervals of time are similar on the Davison and Ford Expressways.
2. Traffic volume affects lane usage and distribution of traffic volume between lanes follows very definite patterns.
3. A method of estimating various twenty-four hour percentile minute volumes when applied to the Davison and Ford Expressways gave similar satisfactory results.
4. Average lane speeds fluctuate very little during the twenty-four hour period except during early morning hours and during high density traffic flow.
5. The distribution of minute average speeds for all lanes of the Davison Expressway and for lanes 1 and 2 of the Ford Expressway are similar.
6. Increase in traffic volumes reduce the headway distribution range but has little effect on the headway mode.
7. The fundamental characteristics of traffic flow are interrelated and this relationship follows definite patterns.
8. Reducing speeds below 40 miles per hour on lanes 1 and 2 of the Ford Expressway results in added inconvenience to the motorist and a reduction in the ability to carry traffic volumes.

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ENGINEERING LAW APPLIED TO HIGHWAY DRAINAGE

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ABSTRACT

Engineering law is defined as the working knowledge of law which the engineer should apply with confidence in his regular practice. Applications to highway drainage are exemplified after introductory definitions of legal terminology. Although some reference is made to California statutes, basic problems depend on widely applicable common law.

INTRODUCTION

In its broadest sense, 'engineering law' is the law of the land pertinent to the practice of engineering as it effects an engineer professionally and his works physically, in relation to public, to client, to Contractor, their agents or agencies, and their property or other vested rights.

In a more practical sense, we limit the term to that part of the law of the land which the engineer should learn and understand, as an integral part of his professional education and training, with such competence that he can apply it with confidence in his regular practice. He may consult or engage an attorney as a precaution on important matters, or to interpret new law, or to litigate, but these are infrequent exceptions to his daily exercise of legal judgment on what can or cannot be done lawfully, and how or when to do it.

Law derives from many sources,—too many to list in this elementary treatise. For simplicity we will speak of statutory law as that deriving from legislation of constitutions, statutes, ordinances, or codes. Practically as forceful is the common law comprising customs and usages recognized and enforced by courts of law. Statutory and common laws are not always explicit because of contradictions, oversights and ambiguities, so that courts must

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determine the intent of the law makers or the most equitable application to litigants; such determinations may become accepted as case law, particularly if upheld on appeal.

Drainage law derives primarily from the common law, with more and more equity or case law adapting the common law to complications of modern society. The distinction between the two is not always important in engineering applications, except that common law is a set of broad general principles while case law is a set of specific rules for particular premises. A specific rule cannot be applied to a new case unless the particular premises are essentially the same.

Terminology

Most engineers appreciate the importance, particularly in contracts and specifications, of assigning a precise meaning to each generic word. It is equally important in law. In many cases the courts have already agreed on definitions of words or phrases quite different from ordinary engineering usages. For example, the engineer commonly classifies all waters as either surface waters or ground waters, dividing them at the soil or rock surface of the earth, but in law surface waters has a more restricted use. Similarly for flood waters, watercourse, erosion and many others. We will start by defining some of these terms.

Surface waters are those which have been precipitated on the land from the sky or forced to the surface in springs, and which have then spread over the surface of the ground without being collected into a definite body or channel. They appear as puddles, sheet or overland flow, and rills, and continue to be surface waters until they disappear from the surface by infiltration or evaporation, or until by overland or vagrant flow they reach well-defined watercourses or standing bodies of water like lakes or seas.

Stream waters are former surface waters which have entered and now flow in a well-defined natural watercourse, together with other waters reaching the stream by direct precipitation or rising from springs in bed or banks of the watercourse. They continue as stream waters as long as they flow in the watercourse, including overflow and multiple channels as well as the ordinary or low-water channel.

Watercourse in the legal sense refers to a definite channel with bed and banks within which water flows, either continuously or in season. A watercourse is continuous in the direction of flow and may extend laterally beyond the definite banks to include overflow channels contiguous to the ordinary channel. The term does not include artificial channels such as canals and drains, except as natural channels are lawfully trained or restrained by the works of man. Neither does it include all depressions or swales through which surface or errant waters pass.

Flood waters are former stream waters which have escaped from a watercourse (and its overflow channel) and flow or stand over adjoining lands, and they remain as such until they disappear from the surface by infiltration, evaporation, or return to a natural watercourse. They do not become surface waters by mingling with such waters, nor stream waters by eroding a temporary channel.

Navigable waters are those stream waters lawfully declared or actually used as such. Navigable waters of the State of California are those declared

to be such by Statute. Navigable waters of the United States are those determined by the Chief of Engineers to be so used in interstate or international commerce. Other streams have been held navigable by courts under the common law that navigability in fact is navigability in law.

Diversion has two distinct meanings, which will be clear in context. In one, it is the taking of water from a stream for a beneficial purpose (irrigation, water supply, power, etc.), even though a portion may return to the same stream. The other is the deflection of surface waters or stream waters so that they discharge into a watercourse to which they are not naturally tributary. Deflection of flood water is not diversion.

Erosion and scour are the cutting or wearing away by the force of water of the banks and bed of a channel in horizontal and vertical directions, respectively.

Erosion and accretion are loss and gain of land, respectively, by the gradual action of a stream in shifting its channel by cutting one bank while it builds on the opposite bank. Property is lost by erosion and gained by accretion, but not by avulsion when the shift from one channel to another is sudden. Property is gained by reliction when a lake recedes.

Backwater is an unnaturally high stage in a stream caused by obstruction or confinement of flow, as by a dam, a bridge, or a levee. Its measure is the excess of unnatural over natural stage,—not the difference in stage upstream and downstream from its cause.

Concentration, in addition to its general sense, means the unnatural collection or convergence of waters so as to discharge in a narrower width, and at greater depth or velocity.

Easement is a right to use the land of others. It may derive from the common law or be acquired, usually by purchase or condemnation, but occasionally by prescription or inverse condemnation. The right is not exclusive, but subject to rights of others in the same land, the lesser right being servient to a prior right which is dominant. Easements for drainage may give rights to impound, divert, discharge, concentrate, extend pipelines, deposit silt, erode, scour, or any other necessary consequence of a highway development.

Use of land of others without right usually leads to right in the future. If use is adverse and notorious for a statutory period, an easement is acquired by prescription, without compensation, but at any earlier time the owner of the other land may sue for compensation by inverse condemnation.

Ground water is that situated below the surface of the land, irrespective of its source and transient status.

Subterranean streams are flows of ground waters parallel to and adjoining stream waters, and usually determined to be integral parts of the visible streams.

Percolating waters are those which have infiltrated the surface of the land and moved slowly downward and outward through devious channels (aquifers) unrelated to stream waters, until they reach an underground lake or regain and spring from the land surface at a lower point.

Artesian waters are percolating waters confined below impermeable formations with sufficient pressure as to spring or well up to the surface.

Perched waters are percolating waters detained or retained above an impermeable formation, so as to stand above and detached from the main body of ground water.

Swamps are lands saturated by ground water standing at or near the surface. (If the water has risen to the surface at a fault, the swamp is a cienega.)

Marshes are lands saturated by waters flowing over the surface in excess of infiltration capacity, as in sloughs of rivers and tidal channels.

Owner herein means any owner of land, usually specified in relation to another owner. Of two owners affected by flow of water, the one upland is the upper owner, the other the lower owner. The highway has an owner, with the same rights in common law as private owners.

Law and Fact

The engineer applying rules of law to highway drainage must bear in mind the distinction between law and fact. The matter is most important in litigation, where questions of law are decided by the judge and questions of fact are resolved by the jury. The judge is an expert on questions of law and he can hardly overlook any pertinent statute or precedent when two aggressive and highly competitive attorneys lay their briefs before him. On the other hand, the jury is likely to have little qualification, individually or collectively, to decide questions of fact. There will be contradictory and confusing testimony on each question with qualified experts contradicting each other, and the attorney with the weakest evidence trying deliberately to confuse the issue.

One such question of fact is whether or not certain water was flowing in a natural watercourse; if so, the waters were stream waters and damage was compensable; if not, the waters were flood waters and damage was not compensable. A 7-to-5 vote one way or the other might determine the entire case. Backwater is also a question of fact. With few exceptions, highway crossings restrict or obstruct channels and cause some backwater; if the highway engineer testifies that the backwater is 2 in. and plaintiff's engineer calls it 2 ft, the jury has to decide which expert is right.

The most important question of fact decided by the jury is the amount of damage. It is notorious that if a private owner sues the State and wins, the award is generous, but if the State is the injured party with the same apparent facts, the State loses or collects only a nominal award. So the engineer must not only distinguish between law and fact, but be aware of the "facts of life."

Surface Waters

By the common law, the upper owner has an easement over lands of a lower owner for surface waters to flow or escape from his land by natural ways and routes.

The upper owner may not, without liability, change the point of discharge of surface waters, nor concentrate them in ditches, nor divert in that direction waters which would have escaped in another direction, nor discharge them at higher velocity, nor add to their pollution. He may, however, increase their quantity by roofing or paving over pervious soils, or by levelling his land so as to eliminate puddles and ponds. Likewise, he may decrease the quantity by retention for his own use, but risking loss of his easement.

The lower owner may not, without liability, obstruct natural flow of surface waters on to his land, either by excluding it or causing backwater on his neighbor.

The highway owner may be in either position, with substantially the same rights and liabilities in law. As a lower owner, he intercepts and receives surface waters in cuts and must arrange to pass such waters under his fills. Then, as an upper owner, he must add to the waters so received the on-site precipitation, and discharge all to a lower owner as he would have received them naturally, or in some other way without damage, or in some damaging way with compensation. The fact that pavement is impervious and sheds more of the precipitation does not add to liability per se.

This problem of disposal of surface waters is one of the most difficult tasks in highway design. If the lower owner formerly received them as sheet flow, it will generally be impractical to spread in the same way the water intercepted by and precipitated upon the highway and collected in gutters, ditches and other drainage facilities. In a thorocut, water would have to be pumped over the lower face of the cut. On a sidehill cut, the water would have to be discharged over the outer shoulder to run in sheet flow down the fill slope. On a thorofill, water carried through the fill in conduit would have to be dispersed in some sort of an outlet trough to spread out on the lower land.

The usual solution is to collect the surface waters in small concentrations and convey the concentrations to a natural watercourse. In built-up areas, the waters may be discharged in a storm sewer. In rural areas there may be no objection to discharge of small concentrations on marginal lands; use is also made of small spreading areas and recharge wells to sink the water into the ground. In mountain and desert areas the problem is obviously simpler. Unusual care must be taken in suburban areas where future changes in land use must be anticipated.

The foregoing applies to State and County highways, but procedures are usually different in municipalities. If by ordinance a city establishes grade along the property line of a street, it can improve the street to that grade without liability to owners of abutting property lying above or below the established grade. Also the pattern of a street system is more adaptable to disposal of collected surface waters than the pattern of rural highways.

An analogous procedure is used in subdivisions, even outside of incorporated cities. By grading all streets before selling lots, the subdivider effectively establishes a de facto grade which purchasers of lots accept, including the consequent drainage.

Stream Waters

Where natural watercourses are unquestioned in fact and in permanence and stability, there is little difficulty in applications of law. Highways cross the channels on bridges or culverts, usually with some constriction of the width of the channel and obstruction by substructure within the channel, both causing backwater upstream and acceleration of flow downstream. These changes in regimen must be so small as to be tolerable by adjoining owners, or those owners must be compensated.

Highways often discharge surface waters into the most convenient watercourse. The right is unquestioned if those waters were naturally tributary to the watercourse and unchallenged if the watercourse has adequate capacity. However, if all or part of the surface waters have been diverted from another watershed to a small watercourse, <u>any</u> lower owner may complain and recover for ensuing damage.

Applications of law become more complicated when the regimen of a channel is changed by other owners. If, for example, upper owners change the character of the watershed so that stream waters are increased in volume, lower owners are obliged by the common law to accept the increase, there being no diversion. They are not obliged to improve the channel through their lands, although they may choose to do so for self protection. Unsettled is the question whether or not an upper owner can compel a lower owner to improve his formerly adequate channel if the increased flow is detained and backs up on lands of the upper owner. Where the lower owner is the highway which had provided an adequate bridge or culvert, some contend that the facility should be enlarged promptly on demand of the upper owner, while others insist the highway has the optional alternative of maintaining the overtaxed facility,—at least until some substantial change was required by reconstruction of the highway itself or retirement of the facility at the end of its useful life. The latter contention is supported, for State highways, by constitutional law against use of highway funds for non-highway purposes, that is, for benefit of private property.

Equally important and also unsettled is the right of a lower owner to completely obliterate a natural watercourse in the process of planing his land for agricultural purposes. Section 725(b) of the Streets and Highways Code is clear on the law, but the question of there having been a watercourse is one of fact left to a jury.

Law does not define any measure of adequacy for improved channels. The highway does not escape liability for obstruction of a channel by providing a bridge or culvert to convey a 30-yr flood, or a 100-yr flood, or even a 1000-yr flood. In common law, such an extreme event might be called an "act of God", defined as "a direct, sudden, and irresistible action of natural forces, such as could not humanly have been foreseen or prevented." However, such a plea is a weak defense in claims for damages, for engineers foresee and can provide for stream waters of great magnitude. Law does not prescribe the provision, which is left to engineering economics.

Flood Waters

The law with respect to flood waters is the simplest of all, but the definition of such waters must be read with attention to every word. They are not simply storm waters, or floods, or cloudburst floods, or overflows, or errant, migrant, or vagrant waters. Surface waters do not become flood waters, no matter how fast, or deep, or where they flow, unless enroute they have entered a natural watercourse and escaped. They have not escaped if they run in an overflow channel or in an outer slough of a threaded channel. They are flood waters only if they have been stream waters and have completely escaped from the natural watercourse, including its collateral channels.

In common law, such waters are a "common enemy" of all people, lands and property attacked or threatened by them. Each and every one, including owners of highways, can act in any reasonable way to protect himself and his property from the common enemy. He may obstruct its flow from entering his land, backing or diverting water onto lands of another without liability. He may discharge such water from his land onto the land of his neighbor

*This citation and others which follow refer to laws of California.

without penalty,—by gravity or pumping, by diverting dikes or ditches, or any other reasonable means. "Reasonable" appears to mean any expedient except destroying your neighbor's defenses, as by dynamiting his levees.

By the definition, flood waters are not necessarily infrequent occurrences. Where frequent, the highway may be designed to obstruct, divert, or pass the flow, without liability to abutting or other owners. There is some risk that frequent flow of flood waters might lead to finding by a jury that the path was in fact a natural watercourse. In historical times some such paths have become main channels (e.g. Los Angeles River and Los Gatos Creek).

Ground Waters

Any interference by a highway with flow or stage of ground waters may be cause for complaint with claim for relief. Excavations, particularly thorocuts, have drained away ground waters which had been pumped for irrigation supply. The supply might remain adequate at a lower level, increasing pump lift.

Embankments may compress underlying water-bearing soils and restrict the percolation of ground water from one side to the other. On the side of the source, the water table may rise to the surface and waterlog the land, while on the other side wells may go dry and owners be compelled to drill deeper and pump higher.

Both State and local laws restrict operations which may pollute or contaminate ground waters used for domestic or irrigation purposes. Plans for disposal of surface waters by spreading ponds or recharge wells must comply. There are allegations of 3 hazards: (1) contamination from highway litter may reach and spread in the ground water, (2) hydrocarbons from road oils and vehicle exhaust may mulsify in and clog aquifers, and (3) drainage from road metal may clog aquifers by calcination.

Unnatural Waters

As a general rule waters other than flood waters which have been forced out of natural pools or paths by the works of man become a responsibility of some person or agency who must divert, store, use and waste such waters without damage to others. Highways may be affected in all degrees from the monumental reservoir which may inundate a roadway down to the sprinkling of laws so as to drain excess water on the pavement. Intermediate are canals carrying water for irrigation of land, drains carrying the return water back to natural channels, and conveyance and ponding of water for power, mining, navigation, flood control, industry, sanitation and recreation. The common law has been clarified and modified by statute, recognizing some uses as "higher" than others.

The Streets and Highways Code,* § 725-730 and § 1487-1488, protect State and county roads respectively. No one may drain or permit drainage of (unnatural) water on highways (725a), nor store or distribute (unnatural) water so that it overflows or seeps onto the highway (725c), if damage results,—and the State may act to obtain relief (726-727). Negligent, willful or malicious acts are misdemeanors (1487 and Penal Code § 588). Note, however, that city

*See note, page 28.

streets are not covered by these statutes; unnatural water is usually allowed to flow into gutters and storm sewers, but such flow may be restricted by local ordinance.

Enforcement of these statutes is not simple, even for flagrant violations. Most abutting owners, through misinformation, believe highways, like city streets, are public drains. Jurors have similar beliefs; even after stern instruction by the Court, they remain sympathetic and return verdicts for only nominal damages. Application of these laws by the maintenance engineer can be greatly simplified if the design engineer establishes grade higher than abutting lands and provides adverse grade and roadside dikes to exclude drainage from depressed roadways.

Several statutes govern canal and ditch crossings (S & H Code § 728-729, 1489-1490; Water Code § 7030-7033). The general rule may be stated, "First in right is first in might", that is, if the canal is there first, the highway must cross it without undue obstruction of flow, but if the highway is there first, the canal owner must provide a crossing without undue interference with traffic. In each case the new tenant pays the cost and is responsible for future maintenance, repair, replacement and removal if abandoned,—except as specified in WC § 7033 for "permanent" construction.

These statutes are not specific for expansion of facilities, that is (1) if a canal is built through an existing highway and the highway is widened, who pays for widening the canal bridge? or (2) if a highway crosses an existing canal and the canal is enlarged thereafter, who pays for the enlargement of the bridge? An obvious answer is that the active party always pays unless the passive party is specifically obligated. For example, if a highway has secured right of way for a divided roadway but built only half when a canal builds across, the permit for the canal may require immediate or future construction of a facility for the ultimate highway construction.

Status of Channels After Sustained Change

Channels may lose their character as natural watercourses through natural or artificial changes that appear to be permanent. Natural avulsions of short reaches of meandering streams are quite common. Complete diversion of a stream (Owens River) was held to quit former rights to discharge water in its former channel or terminal lake. It has been contended that partial regulation of a stream so as to limit its maximum discharge abandons the right to restore the full natural flow at a later date, but this question is unsettled.

Application of this rule and the latter contention to highway practice may be very confusing. Obliteration of a watercourse by land planing on one side may impound water against the other side of the highway and over abutting lands, damaging those lands and diverting overflow to another watercourse. The highway owner may be held at fault for not acting to stop the land planing. As an example of the other matter, when upper owners complained that a highway culvert was too small, causing overflow of their lands, plans for enlarging the culvert were stopped by threat of injunction by a city (Fairfield), which alleged that lower owners in the city would be injured by overtaxing of the channel which had been improved to match the capacity of the culvert.

These contingencies cannot be avoided entirely, but their number should be substantially reduced by alertness and prompt action by maintenance engineers. Land planing is tolerated in its effect on surface waters, but

S & H § 725 (b)(1) forbids it for natural watercourses unless other drainage is provided.

As a corollary, artificial substitutes for natural watercourses may be held to be natural watercourses after long sustained use. There is no statute nor other rule to fix the minimum of time to measure permanence of change, but it may be presumed that a Court would consider prescriptive periods, or general acceptance of the change, or obliteration of other channels.

Inverse Condemnation

In most matters, public agencies cannot be sued without their consent. An important exception is the suit in inverse condemnation, alleging that private property has been taken without just compensation. The agency could have taken the property by eminent domain by a suit in condemnation to prove public necessity for the taking and determine the value of the property taken, but often some properties are overlooked or considered speculative or intangible, so that the owners initiate the eminent domain action inversely. Easements for drainage are notable among such properties.

Engineers will frequently be called upon to prepare and present evidence in the defense of such suits, at which time they will be well advised by attorneys. The real defense, however, should begin long before suit is filed, at a time when the engineer is acting on his own initiative. This defense is an accurate knowledge of the conditions of lands along the projected highway, so as to show the change in conditions after the highway has been constructed. For lack of good evidence (maps, photos, notes of competent observers) juries will believe the highway caused all damage cited in the complaint.

Liability for Negligence

Damage to private property by flooding or erosion may be due to negligence instead of an involuntary taking of a drainage easement. Complaints of damage due to negligence must allege fault or default of one or more employees, contending as a minimum (Government Code* § 1953):

a. There was a defect and it caused damage
b. An employee was responsible for the defect, or had notice of it.
c. He had authority, duty and funds to repair it
d. He did not promptly repair or warn of the defect
e. Claimant was not also negligent

Negligence in highway drainage may derive from errors of omission or commission in design, construction, operation or maintenance. In none of these fields is the engineer infallible in skill or judgment, but he must have acted with the care, skill, judgment and diligence ordinarily exercised by professional engineers. Deficiencies which have caused complaint are:

a. Poor estimate of design discharge
b. Not conveying discharge to an acceptable outfall
c. Allowing inlet to become obstructed
d. Allowing pond to form where a person drowned
e. Building a weak structure

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*See note, page 28.

f. Building an open storm inlet too near the highway
g. Not providing drainage for a depressed street
h. Underestimating size and volume of drift
i. Permitting traffic through dangerous overflow.

Calculated Risks

Although more closely related to engineering economics, the taking of calculated risks must be considered an important item in drainage law. The question may arise as to liability for negligence.

The expression is confusing to some engineers because of the use of the word 'calculated' in a sense unusual to them. It does not mean 'computed' on a calculating machine, nor even reduced to numerical values, although such techniques may be part of the calculation. It really means considering with knowledge, prudence and judgment all the hazards, perils and other risks involved in a proposed course of action, together with difficulty of avoiding these risks. Taking the calculated risk means acceptance of the risk instead of a different course of action with less risk but greater difficulty.

This is permissible in law. In drainage, particularly, there is no course of action without risk, even if we design for the maximum possible flood. Economy demands design for a smaller flood. Prudence demands design for a flood which does not recur too frequently. Between those two indefinite extremes, there must be a sound basis for design. If all the hazards and perils could be foreseen precisely and expressed numerically, the design could mathematically minimize cost of facility plus present value of the risk. Unfortunately these risks are highly speculative, and the engineer is forced to a 'calculated risk'.

The question of negligence arises after an injury allegedly caused by a deficiency in design. Not to have foreseen the injury might have been negligence, but to have foreseen the possibility and weighed it with other factors is a proper exercise of judgment. If the injury is to real property, there may have been a taking, leading to compensation by inverse condemnation, but injury to a person or a vehicle depends on proof of negligence.

Regulation by Public Agencies

In addition to propietary rights, which are a matter of record, many public agencies have responsibility and authority over certain operations on natural waters and channels which may affect highway drainage. Without exaggeration, the number of such agencies in California alone exceeds 1000. Fortunately the complexity due to numbers of agencies is offset by specific definition of their powers in statutes.

One such agency is the State Division of Lands which administers the State's ownership of beds of navigable waters of the State of California, listed in Harbor and Navigation Code* § 102-106. Its permit or easement must be obtained for crossings over such waters, channel changes, dredging, etc., (S & H Code § 101.5).

Another is the State Reclamation Board with its regulatory powers (Water Code § 8710) over operations "in the bed of or along the banks of the

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*See note, page 28.

Sacramento or San Joaquin Rivers or any of their tributaries or connected therewith, or upon any land adjacent thereto, or within any of the overflow basins therein, or upon any land susceptible to overflow therefrom." This broad definition covers all of the central valley, from Shasta to Tehachapi and Clear Lake to Donner Summit, within which, literally, permission must be sought for every embankment or excavation, even to digging a hole to plant an oleander in a highway median. Obviously, administration is not so literal, being limited to the intent of the law to improve and maintain natural channels, canals, drains and floodways by dredging and leveeing. Pending draft of a more realistic definition, an informal procedure has been set up at staff level for advance determination of the Board's interest in particular channels. Cooperation with highway funds is limited by S & H Code § 101.3.

In highway drainage, water is a liability, but drainage works cannot ignore the value of water as a natural resource. The Department of Water Resources administers the right to use water and must be consulted when drainage plans conflict with conservation or distribution projects. The Department is also responsible for supervision of dams, and although highway embankments are specifically excluded from the definition of a dam (Water Code § 6004), check dams require permits if certain minima are exceeded (a 6-ft dam impounding 50 ac-ft or a 25-ft dam impounding 15 ac-ft, Water Code § 6002-6003).

Mention should be made of the Department of Fish and Game because of its interest in natural waters traversed by anadromous fish. Migration of fish may be stopped at highway culverts, particularly at low water, if the invert is flat so as to shoal the flow, or if excessive drops cannot be jumped by the fish. There is no statute requiring adaptation of culverts to migration of fish, so highway funds cannot be used for the purpose. However, it will usually be possible to establish flow line and shape invert to accommodate fish at no extra cost. Inverts have been built V-shaped. Multiple culverts have been built with one unit lower than the others. Flow lines have been lowered to avoid drop to a pot-hole at the outfall. Usually unacceptable are proposals for fish ladders and slalom battens inside the culvert; not only do these require improper use of highway funds, but they trap drift and detritus, reducing the capacity of the culvert and adding to the cost of maintenance.

Mention should also be made of the State Water Pollution Control Board, and its regional agencies. No specific statutes or regulations require highway cooperation, but drainage facilities in certain locations may violate general provisions of the law (Water Code § 13000 et seq). Flushing hydrocarbon residues from highway pavements into natural watercourses may be "pollution". Detention at highway culverts of waters polluted by others may be "nuisance". The law is too new to predict interpretation by the courts.

Most numerous of the agencies referred to are the "Districts" organized under State law. Geographically, they are widely distributed over the State, vary in size from less than a mile to more than 100 miles in length, and frequently overlap for two or more distinct purposes benefitting the same lands. The following classes of Districts may have a regulatory or discretionary interest in highway drainage:

County Flood Control Districts	Water Code § 8110
Special Drainage District	8500
Irrigation Districts (112)	20500
County Water Districts (90)	30000
California Water Districts (21)	34000

California Water Storage Districts (4)		39000
Reclamation Districts (180)		50000
County Waterworks Districts (63)		55000
County Drainage Districts		56000
Drainage Districts (20)	Deering	2200-03
Flood Control and Flood Water Conservation (3)		9178
Levee Districts (11)		4284
Municipal Water Districts (17)		5243, 9131
Protection Districts (2)		6172, 74, 75
Storm Drain Maintenance Districts (14)		2208
Storm Water Districts (8)		6176
Water Conservation Districts (16)		9127
(S) Conservation District (1)		4025
(S) County Flood Control District (6)		3515 et al
(S) County Flood Control and Water Conservation (14)		205 et al
(S) County Storm Drainage District (1)		1657
(S) County Water Agency (2)		6730, 7303
(S) County Water District (2)		5683, 9124
(S) Flood Control District (2)		320, 6749
(S) Sanitation and Flood Control District (1)		8934

(S) indicates districts created by special statute.
Number of districts active in 1953 shown in ( ).

Many Federal agencies are concerned with drainage affecting proprietary rights in public lands and reservations, but only one need be mentioned for its jurisdiction over other matters affecting drainage. The Corps of Engineers is responsible for administration of navigable waters of the United States, for operation of Federal flood-control projects, and for control of debris in certain streams.

The Corps is currently classifying navigable waters into two groups. One will be those used only by small craft, such that highway structures clearing flood stages will assuredly provide adequate clearance for navigation at ordinary stages; no formal permit will be required. For the other group, the procedure will be formal, beginning with a detailed application for permit to cross, public hearing to weigh conflicting interests of highways and navigation, economic analysis of relative costs and benefits, and ending with a determination of minimum horizontal and vertical clearances.

On Federal flood-control projects, the Corps builds dams and improves channels for operation by local agencies according to a specified set of regulations. The local agency becomes the proprietor with authority to approve plans for highway crossings of flood-control channels, but it will usually refer applications to the Corps for comment before taking action. Preliminary informal discussion of alternatives directly with the Corps will expedite formal action later.

With respect to all public agencies, their works and most of their projects are matters of public record. Courts have held that highway engineers should recognize the probable effect of completed works and assured projects in their own design of drainage facilities. It is a matter of discretion, however, as to whether a project is assured at any particular stage of investigation, authorization, appropriation, or construction. Several large dam projects

were abandoned after attempted construction disclosed weak foundation rock. Debris reservoirs have filled up in the first storm. Completed levees have been overtopped.

SUMMARY

In this cursory treatment of drainage law, emphasis has been laid on principles which can be applied by the highway engineer in his everyday practice. If engineers hesitate to apply these principles without counsel, they should recall the classical "proof" that even lawyers are right only half the time, since every case has both a winner and a loser. Also, the engineer seeking counsel on every legal question may often be advised not to do something because of uncertainty of right. Unless he knows the degree of uncertainty, he cannot take the calculated risk which may be the most economic solution.

No attempt has been made to cite cases in support of principles of law. Three references (McCullough, Durkee and Williams) have done so and should be consulted for further understanding of the exact circumstances which prompted statements of principle.

References to statutes are limited to laws of California. Those from the Streets and Highways Code are similar in many other states, but those from the Water Code are similar only in other western or arid states. In any case, applications of principles should conform to local law.

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2. Memorandum Discussion of Rules of Law Respecting Waters, Applicable to Problems of Highway Drainage, Frank B. Durkee (Mimeo, May 29, 1946, California Division of Highways).

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PASSENGER DATA FOR URBAN TRANSPORTATION PLANNING

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SYNOPSIS

"Urban Transportation" encompasses such a wide variety of non-competitive types of freight and passenger movements into, out of, within and through urban areas as to make complete integration, as a means for solving urban transport problems, far more formidable than those it is meant to solve.

An analysis of changes in selected, realistic, homogeneous segments of trans-Hudson passenger movements in a postwar decade (1948-58) has revealed:

1. That travel to and from the Central Business District (CBD) has shrunk.
2. That largely as a consequence, rail travel, has shrunk.
3. That the CBD is <u>the</u> area for which mass transit on rails has been built, which area, rails still serve best and to and from which area, rails still handle the "lion's share", <u>but</u> of a declining travel "market".
4. That other segments of urban travel such as "reverse" travel and peripheral travel have been expanding, <u>but</u>
5. That these segments are best handled by mass transit by interurban buses or by automobiles, and hence travel by interurban buses and autos has been expanding, on the other hand
6. That <u>existing</u> mass transit on rails is today a slower and more inconvenient mode of travel for such urban linkages, and hence rail travel has been declining.

If communities wish to take advantage of the economies of <u>existing</u> mass transit on rails, where there is already sunk capital, they should encourage redevelopment of sites of employment in areas where the existing mass transit would be more attractive than the automobile. They must also actively help bring into being good mass transit by interurban buses to such newly developed sites of employment.

Note: Discussion open until May 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2275 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. HW 4, December, 1959.

1. Economist, The Port of New York Authority, New York, N. Y.

"Urban Transportation" covers a wide variety of activities. Urban areas themselves may vary widely from a single city to several cities in a metropolitan district or even a tri-state region like the New York-New Jersey-Connecticut Region.

Transportation covers the movements of people and goods into, out of, within and through urban areas, by all modes. It thus envisions movements of people and goods on waterways, railways, airways, as well as highways—movements of some types of goods even in pipe lines.

The vehicles which handle these movements in urban areas, constitute the traffic flows of these areas. For example, there are the vessel movements into, out of and on their harbor waterways; movements of freight and passenger trains along the trackages throughout the areas; the airplanes and helicopters flying along their regional airways as well as auto, bus and truck volumes along their regional highway systems.

Planning for urban transportation must, of course, consider the operations at existing terminal facilities that now handle movements of people and goods. There are the steamship piers, quays and docks that handle waterborne passengers and commerce; railroad passenger and freight stations, terminals and supporting classification yards, that handle railroad passengers and freight; airports and heliports with their approach highways, that handle air passengers and cargoes, as well as regional highways and highway approaches, major arterials, vehicular bridges and tunnels together with intercity truck and bus terminals, that handle auto and bus passengers and truck freight.

To reflect all of these continuing transportation activities in urban areas, control statistics of passenger freight and cargo movements must be continually assembled and expressed in the usual commercial units employed by the various transportation media. Thus, data on waterborne commerce, expressed in long tons, must indicate over-all volumes of cargoes handled into and out of urban areas (functioning as ports) and such cargo volumes must be separated as between domestic and overseas, inbound and outbound, and by groups of commodities. Data on railroad freight expressed in short tons, must indicate freight movements inbound, outbound, and through urban areas (functioning as rail centers) and such freight statistics must be separated by groups of commodities, if available.

Airlines should furnish their passenger statistics separated between domestic and overseas air passenger movements. Similarly, data on rail passenger movements must be assembled for the several railroads that serve urban areas, and they must show such movements divided between commuters and "others" which latter group would include short and long haul single trip riders. Again, bus passengers must be assembled from individual long and short haul bus lines.

To be effective for planning purposes, freight and passenger statistics for common carriers must not be on a common carrier "system" basis, but rather on an into-and-out-of-the-urban-area basis. This requirement usually necessitates specially assembled local statistics, if they are to be useful for planning purposes.

"Planning for Urban Transportation" must contemplate multitudinous transportation activities within urban areas, conducted in the course of handling people and goods by a number of radically different modes of transportation, operated over the greater part of urban areas, and with widely varying linkages within as well as between such urban areas, and outside localities with which they maintain a community of interest.

"Urban Transportation" thus covers such heterogeneous volumes of non-competitive types of passenger and freight movements, as overseas air passengers and intercity bus passengers, overseas general cargo and truck movements of LTL freight; such widely varying terminal facilities as regional highways, airports, railroad passenger stations, freight classification yards, and deep sea steamship piers and wharves; such widely different organizations as railroads, airlines, public authorities, state highway commissions, and state and federal regulatory agencies.

Advocates of "Integration of Urban Transportation", as an effective solution for existing urban transportation problems might well contemplate this spectrum of urban transportation activities, make a serious effort to visualize the size, scope and type of an over-all operating organization which would be required to plan, finance, construct, operate and regulate a comprehensively integrated urban transportation system, in a manner such as to solve all of our various types of urban transportation ills. Such advocates might also realize that certain existing financially strong segments of the urban transport system, if forced to combine with financially weak segments, would effectively preclude the future financing of the presently strong segments of the system that are now being successfully financed and operated.

It is manifestly beyond manageable proportions to discuss, in this paper, the various types of factual data required to plan for all of the types of urban transportation mentioned above. It is therefore proposed to limit this paper to a discussion of regional passenger transportation data, using as an illustration the experience of passenger travel in one section of the New York-New Jersey Metropolitan District.

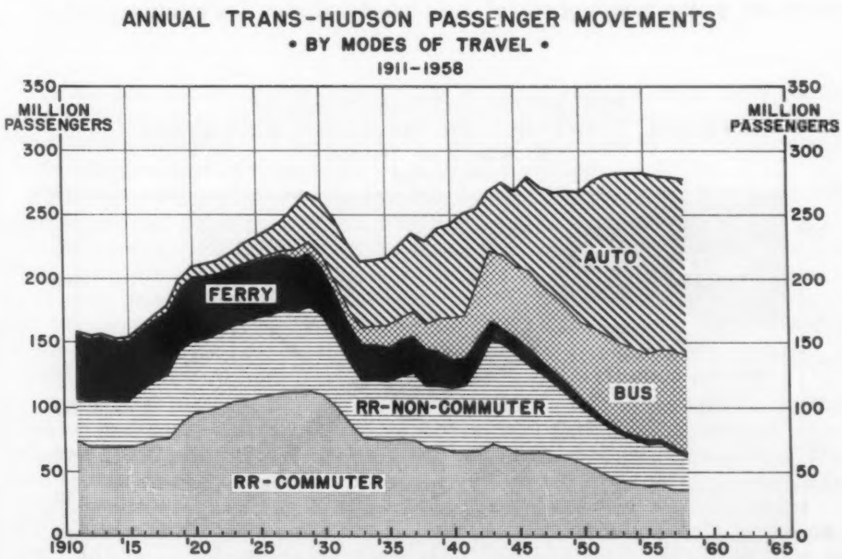

Fig. 1

Trans-Hudson Passenger Movements

The Port Authority, being a bi-state (New York-New Jersey) public agency, has concentrated on interstate passenger movements. Consequently, data on annual passenger movements across the Hudson River which separates the States of New York and New Jersey within the New York Harbor, have been assembled over the years. These data show annual interstate passenger movements via railroads, in buses, in autos and as ferry pedestrians, continuously for a period of several decades.

It is quite evident from Figs. 1 and 2, that for the past three decades railroad passenger movements have been declining steadily both in absolute volumes and relatively, except during World War II; passenger movements in buses and autos on the other hand, have been expanding. From an inspection of these charts, it is tempting to jump to the conclusions that railroad passengers have been disloyal to the railroads, have been deserting them in droves, and have been taking to automobiles on the highways. Digging down some statistical strata below these summary annual figures for specific years for which more detailed sample data are available, reveals more rational explanations of the travel habits of interstate passengers who crossed the Hudson River.

Decade Changes in Trans-Hudson Passenger Movements

Selecting two Postwar II years, 1948 and 1958, a decade apart, it has been possible to some extent to break down statistics on annual trans-Hudson passenger movements in these two years, timewise and spacewise, into realistic homogeneous segments. Examining the over-all changes in this 10 year interval by major modes of travel, it is found that they are fairly typical of

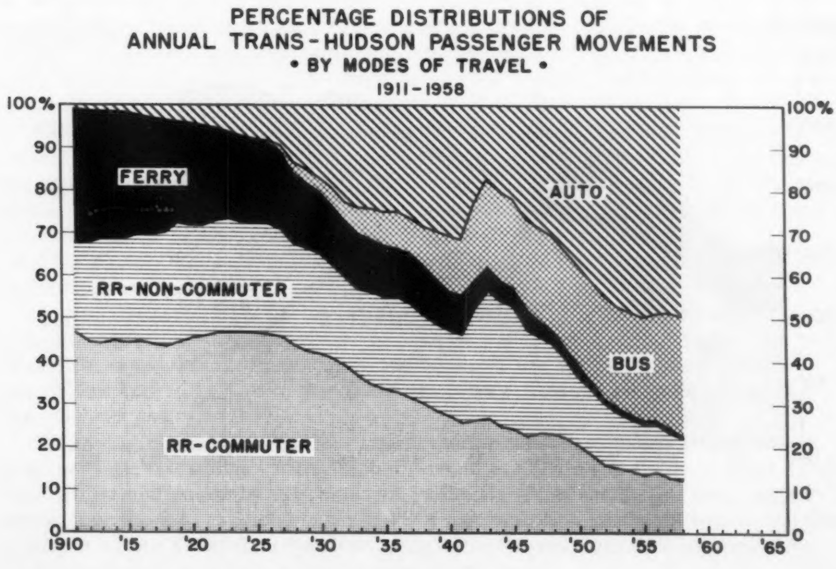

Fig. 2

the continuing changes that have been occurring over the postwar years. Thus, trans-Hudson movements of railroad passengers and pedestrians via Hudson River ferries in the 10 year interval 1948-1958 have shrunk; movements of passengers in autos and buses have expanded. This will be seen in Table 1 following.

TABLE 1

DECADE CHANGES (1948-1958)
IN ANNUAL TRANS-HUDSON PASSENGER MOVEMENTS
BY MODES OF TRAVEL

	All Modes	In Autos	In Buses	Ferry Ped'ns	In RR's
		(M i l l i o n s)			
1948	266.6	80.7	60.1	8.3	117.5
1958	276.8	136.4	76.9	1.4	62.1
Changes 1948-58					
Number	+10.2	+55.7	+16.8	- 6.9	-55.4
Per cent	+ 3.8%	+69.0%	+28.0%	-83.1%	-47.1%

In the above table, it will be seen that in the 10 year interval, there was an overall increase of 10 million passenger movements, or less than four per cent for the decade; auto passenger movements expanded by 55.7 million while railroad passenger movements shrank by 55.4 million.

For these two typical years, a decade apart, it is also easy to jump to the conclusion that autos have drained the railroads of their former passengers. An analysis of the more detailed statistics available for these two years, however, compels one to qualify this conclusion quite radically.

Let us look at the more detailed statistics for these two years. They show the decade changes in trans-Hudson passenger movements via the four major modes of travel but broken down into significant time and space segments. These are shown in Table 2.

In the first place, it will again be seen on line 1 that in the aggregate, trans-Hudson passenger movements by all modes, in the two years, a decade apart, showed a 10.2 million increase or 3.8%. When these passengers movements are broken down into significant segments, however, they show some healthy increases in weekend travel, both by New Jersey and New York residents, 9.1 million (line 2) in travel by New York residents to and from New Jersey, (10.1 million on line 3) and in New Jersey residents traveling to and from New York to areas other than the Manhattan Central Business District (CBD), (8.8 million on line 4). The shrinkage in trans-Hudson passenger movements has occurred entirely in travel to and from the Manhattan CBD (17.8 million on line 5) both in off hours (3.6 million on line 6) and in rush hours (14.2 million on line 7).

TABLE 2

DECADE CHANGES (1948-1958)
IN ANNUAL TRANS-HUDSON PASSENGER MOVEMENTS
BY MODES OF TRAVEL

	By All Modes 1958	By All Modes	In Autos	In Buses	As Ferry Ped'ns	By RR's
			(M i l l	i o n s)		
1. All days	276.8	+10.2	+55.7	+16.8	- 6.9	-55.4
2. Weekends (NY & NJ residents)	86.2	+ 9.1	+21.1	+ 2.6	- 2.2	-12.4
3. NY Residents to & from NJ	55.0	+10.1	+15.6	+ 2.6	- 0.8	- 7.3
4. NJ Residents to & from Non-CBD	31.7	+ 8.8	+10.5	+ 1.2	- 0.4	- 2.5
5. NJ Residents to & from Manhattan CBD	103.9	-17.8	+ 8.5	+10.4	- 3.5	-33.2
6. In off hours	45.8	- 3.6	+ 4.7	+ 4.9	- 1.1	-12.1
7. In rush hours	58.1	-14.2	+ 3.8	+ 5.5	- 2.4	-21.1

Looking more closely at the figures on line 2 and in Fig. 3, note that weekend passenger movements in autos had expanded by 21.1 million, while movements by railroads had shrunk by 12.4 million. It is common knowledge that the weekend traveler has come to depend more and more on the automobile, because of its greater economy for family outings, its greater convenience for reaching amusement and recreation areas far from common carrier routes. These figures of postwar decade changes merely quantify this well known phenomenon as it has manifested itself in the travel across the Hudson.

Again, trans-Hudson passenger movements by New York residents (line 3 and Fig. 4), have expanded by a net of 10.1 million; movements by auto and bus have expanded while those by railroads have shrunk. This has been brought about by the fact that new places of employment and recreation areas have been widely scattered throughout Northern New Jersey.

Examining line 4 and Fig. 5, note that on weekdays between 1948 and 1958, trans-Hudson passenger movements by New Jersey residents to and from New York areas north of 59th Street (north of the Manhattan CBD) and elsewhere in New York, have expanded by a net of 8.8 million. Passengers in autos showed an expansion of 10.5 million, but were offset by a small decline in railroad passenger movements amounting to 2.5 million. This has come about because of the widespread destinations of places of employment, business and recreation areas throughout New York, places that are not directly served by through transit. So, in 1958 some 23.7 million passenger movements were

made by New Jersey residents across the Hudson River in autos to reach these widely scattered areas, about 10.5 million more trips or an 80% increase over the 13.2 million auto trips made in 1948.

The figures on line 5 as well as Figs. 6 and 7 tell a radically different story. Between 1948 and 1958 a net of some 17.8 million fewer passenger movements were made by New Jersey residents to and from the Manhattan CBD. Autos gained only 8.5 million, about 4.7 million in the 18 off hours and 3.8 million in the six rush hours from 7 to 10 a.m. and from 4 to 7 p.m. The large shrinkage, a total of 35.2 million, was in the passenger movements by railroads, both in off hours and in rush hours.

The Manhattan CBD is therefore the area which suffered the greatest shrinkage in trans-Hudson passenger movements between 1948 and 1958. This is the area for which the railroads were originally built and which they have been serving best. But now sites of employment in New Jersey closer to home or in New York areas other than the Manhattan CBD apparently compete with the Manhattan CBD.

The other segments of trans-Hudson passenger movements which have shown healthy increases in the 10 year interval have not been as well served

9,100,000 MORE Weekend Travelers Crossed the Hudson River in 1958 than in 1948

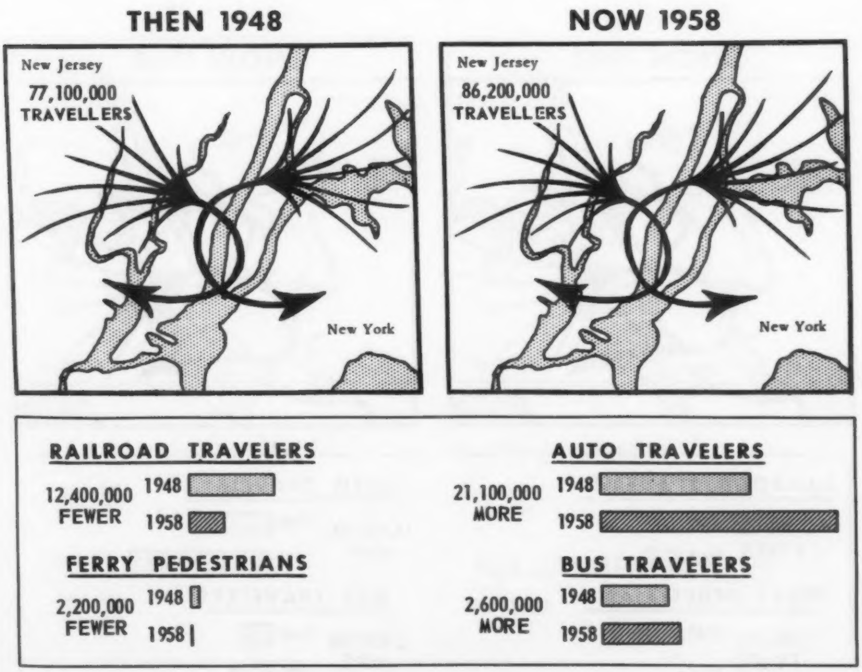

Fig. 3

by railroads, have been better served by interurban buses, have been best served by autos.

This, then, is a sketch of how we got to where we are, as far as trans-Hudson passenger movements are concerned in the decade 1948-1958. It is equally fruitful to examine the travel segments from the viewpoint of where we are, at least where we were in 1958.

Trans-Hudson Passengers in 1958

In 1958, as has been mentioned above, about 276.8 million passengers crossed the Hudson between New York and New Jersey. As will be seen in Table 3, about 50% crossed by auto and 50% by common carrier—in interurban buses and by rail.

From Table 3, one would be tempted again to jump to the conclusion that for trans-Hudson passenger movements the common carriers (buses and railroads) and automobiles are equally convenient, because about 50% of trans-Hudson passengers chose common carriers and 50% automobiles. That conclusion is furthest from the truth as the analyses that follow are intended to show.

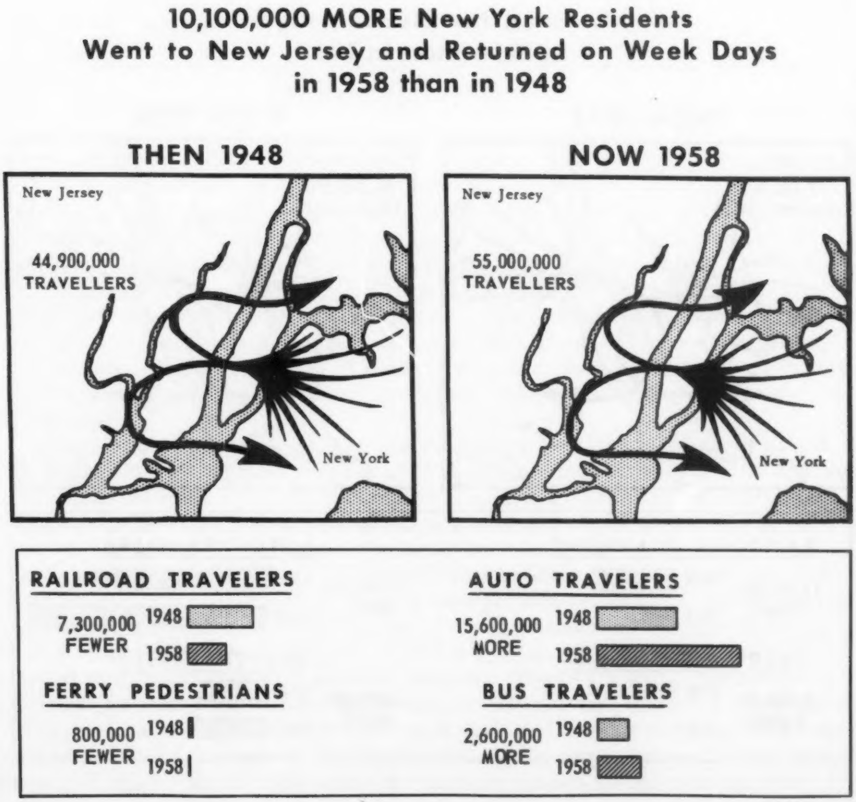

Fig. 4

TABLE 3

TRANS HUDSON PASSENGER MOVEMENTS
BY MODES OF TRAVEL
IN 1958

	Via All Modes	In Autos	Via Bus & RR	Via Common Carriers Bus	RR
	(M i l l i o n s)				
All Days	276.8	136.4	140.4	76.9	63.5 1/
All Days	100.0	49.3	50.7	27.8	22.9

1/ Includes, as ferry pedestrians totaling 1.9 million passenger movements.

8,800,000 MORE New Jersey Residents Went to and Returned from Points North of 59th Street in Manhattan and Elsewhere in New York in 1958 than in 1948

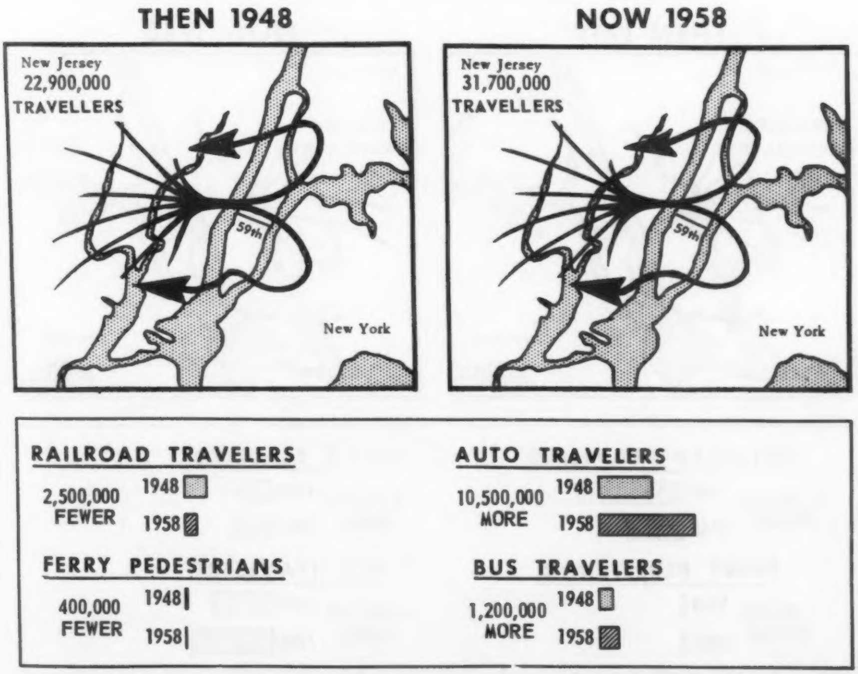

Fig. 5

If the aggregate annual volume of trans-Hudson passenger movements is divided again, into such time and space segments as, for example, along certain linkages of travel between small enough areas and at such time periods when trans-Hudson passengers are confronted with real choices among alternate modes of travel, then the statistics tend to bring into relief more faithful pictures of the real competition that exists between common carriers and autos. Table 4 shows segments of Annual Trans-Hudson Passenger Movements Distributed Among Alternate Modes of Transportation in 1958. The percentages in this table indicate how selected segments of trans-Hudson passengers made their choices among alternate and competitive modes of travel, autos, buses and railroads.

These statistics indicate that trans-Hudson travelers, like most travelers en masse, chose their modes of travel in a manner that reasonably reflected the conveniences of some modes and inconveniences of others for travel between given origin areas of residence at one end and destination areas of travel purpose at the other.

Despite the shrinkages in railroad passenger movements in the past decade, rail transport is still the preferred and dominant mode, where it is the fastest

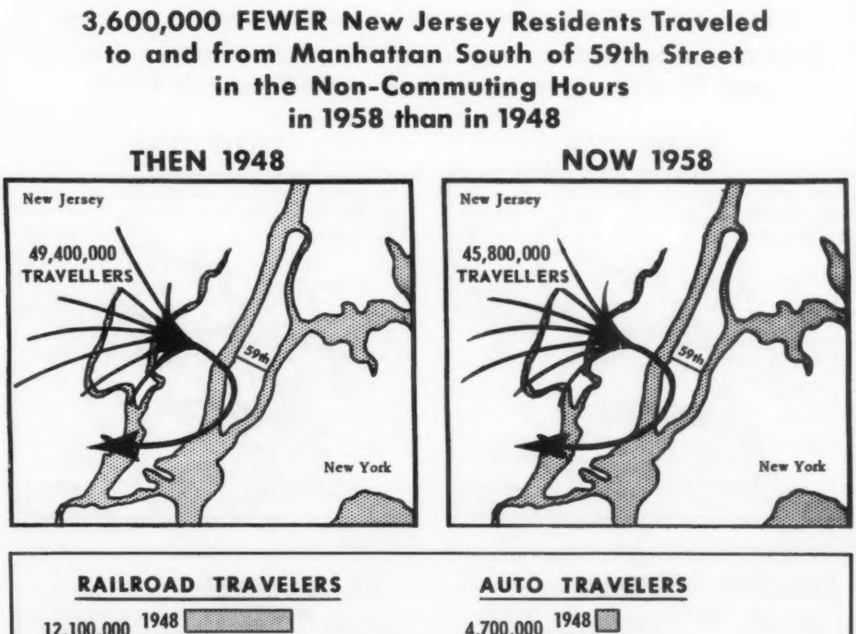

Fig. 6

TABLE 4

HOW SEGMENTS OF ANNUAL TRANS HUDSON PASSENGER MOVEMENTS
WERE DISTRIBUTED AMONG ALTERNATE MODES OF TRANSPORTATION
IN 1958

			By All Modes (Millions)	By All Modes (Percentages)	In Autos (Percentages)	In Buses (Percentages)	In RR'S (Percentages)
1.	All Days		276.8	100.0	49.3	27.8	22.9
	Weekends:						
2.	NY & NJ Residents		86.2	100.0	67.5	22.4	10.1
	Weekdays:						
3.	NY Residents to & from NJ		55.0	100.0	64.0	18.9	17.1
4.	NJ Residents to & from Non-CBD		31.7	100.0	74.8	15.1	10.1
5.	Manhattan CBD: Off Hours		45.8	100.0	23.1	44.3	32.6
6.	Rush Hours: Upper (34th-59th)		24.7	100.0	15.4	57.5	27.1
7.	Middle (Houston-34th)		13.5	100.0	20.7	34.1	45.2
8.	Lower (Battery-Houston)		19.9	100.0	10.6	16.6	72.8
	Weekends:						
9.	NY & NJ Residents		86.2	100.0	67.5	22.4	10.1
10.	Long Haul		21.2	100.0	68.4	17.4	14.2
11.	Short Haul		65.0	100.0	67.2	24.0	8.8
	Areas	Tributary to					
12.	Upper NJ	GWB	23.9	100.0	84.5	15.5	0.0
13.	Middle NJ	LT	24.1	100.0	51.9	45.2	2.9
14.	Lower NJ	HT	17.0	100.0	64.7	5.9	29.4

Note: Underlining thus ____ indicates "lion's share" by one mode or major shares by alternate modes.

and most convenient for travelers, (see lines 8 and 7). These are areas where the railroad station is close to passengers' homes and where their places of business are within easy walks or easy subway rides of railroad terminals at destinations. Where, however, railroad travel is circuitous, imposes a long auto ride from home to the railroad station, and then another long bus or subway ride to reach places of business, passengers naturally seek more convenient alternate routes. If more convenient intercity urban buses are available which can bring passengers from their homes to business faster, with fewer changes and shorter walking distances, at points of origin, points of destination, or both, they will naturally choose buses for those travel linkages, (see lines 5, 6 and 13). If convenient bus transportation, however, is not available, travelers will choose automobiles, (see lines 3, 4 and 12) provided however, that parking autos at destinations are not decided inconveniences.

The above statistics reflect the behavior en masse of trans-Hudson passengers in their travel between areas of residence and areas of purpose. When transportation statistics are thus realistically arranged to reflect travel between residences and purpose zones, like journey-to-work linkages between home and work place, they have invariably revealed that riders have generally

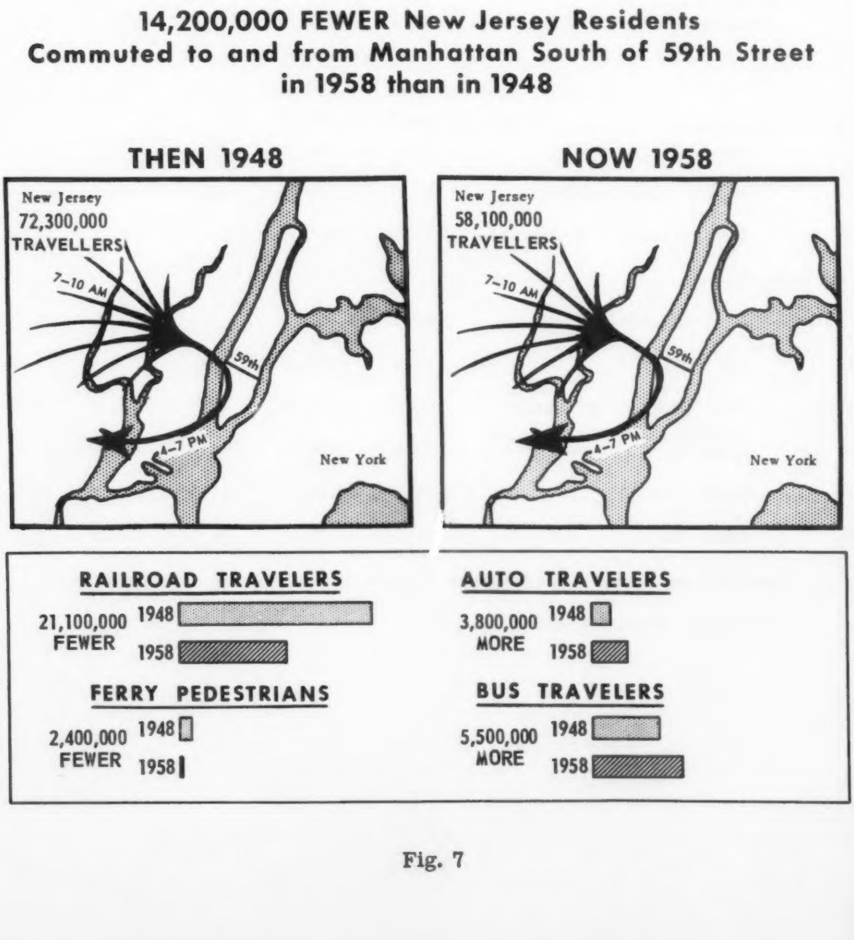

Fig. 7

been rational in their choices of mode. Riders en masse have the wisdom of a Solomon and the patience of a Job. Planners would therefore do well to heed the desires of plannees as manifested by their deeds.

Future Prospects for Commuter Railroads

What, therefore, might the future hold for commuter railroad passenger transportation?

Weekend leisure time travel within any given urban area has been captured for good, largely by the automobile and, to some extent, by the bus. This travel segment is well nigh irretrievable by railroads.

The weekday trans-Hudson passenger segment which, in the New York region consists of New York residents, traveling to and from New Jersey is what might generally be called the "reverse travel" segment. It is comparable in other urban areas to travel by residents of the Central City to and from places of employment and recreation in the outer rings of metropolitan districts. In the New York region this is an expanding segment of passenger movements. It may be elsewhere too. But, this segment presents difficult scheduling problems to railroads. If they were to compete aggressively for such service, it would be necessary for them to schedule trains to get the workers to their benches at the proper time in plants located all along their lines and within easy walking distances from railroad stations. Scheduling such trains to serve effectively a number of specific towns spread out along the railroad line would not be as simple as scheduling trains for concentrated areas of employment, such as CBD, where entire train loads arrive at stations within a few minutes walk or ride to destination. Such train scheduling could be achieved only to a small degree.

MORNING PEAK HOURLY SHORT HAUL
SCHEDULED BUS AND PASSENGER ARRIVALS
AT PORT OF NEW YORK AUTHORITY MANHATTAN BUS TERMINAL
• FOR WEEKDAY SURVEY DAYS •

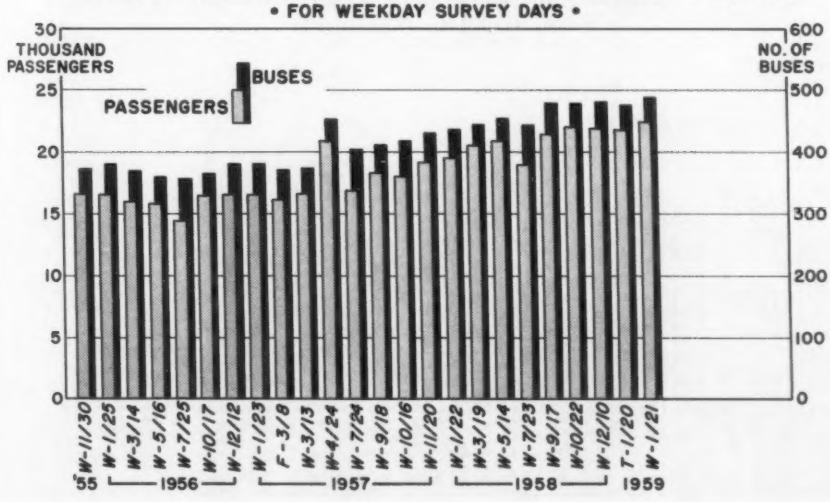

Fig. 8

What in the New York region corresponds to New Jersey residents traveling to and from areas not in the Manhattan CBD, are, in other urban areas, travelers from the suburbs bound for areas outside the CBD. This in the New York area, and perhaps elsewhere, appears to be another expanding travel segment; but this segment, too, is extremely difficult to serve by rail mass transit. The bulk of such travel is not radial, (toward the CBD) but peripheral. Resident zones of origin and purpose zones of destination are widely scattered throughout the entire urban area. Mass transit, even by buses, would find it difficult to serve this segment adequately. However, if a large enough volume of such peripheral movements were to flow most directly through the CBD, then a bus terminal within the CBD, utilized as a transfer station as well as a CBD terminus, might in some instances make mass transit by bus serving such a travel segment, economically feasible.

For example, in the Port Authority Bus Terminal in Manhattan, more than 450 buses arrive regularly on weekdays between 8 and 9 A.M. and bring into the terminal, at an average of about 45 passengers per bus, about 20,000 to 25,000 bus passengers in that rush hour. (See Figs. 8-13, inc.). The 450 buses or so utilize only a portion of a lane in the Lincoln Tunnel with which the Bus Terminal is connected by ramps. More buses could, without difficulty be accommodated in one lane, if it were allocated exclusively (or even preferentially) for buses in any one rush hour. The rush hour bus passenger volume into the terminal compares favorably with the peak hourly volume of passengers that rail transit can handle into a railroad terminal.

Out of the terminal, however, whether it be a rail or a bus terminal, there must be further passenger distribution, if the terminal is located in a large multinuclear Central Business District like Manhattan south of 59th Street. The Port Authority Bus Terminal is within walking distance of many places of

AFTERNOON PEAK HOURLY SHORT HAUL
SCHEDULED BUS AND PASSENGER DEPARTURES
FROM PORT OF NEW YORK AUTHORITY MANHATTAN BUS TERMINAL
• FOR WEEKDAY SURVEY DAYS •

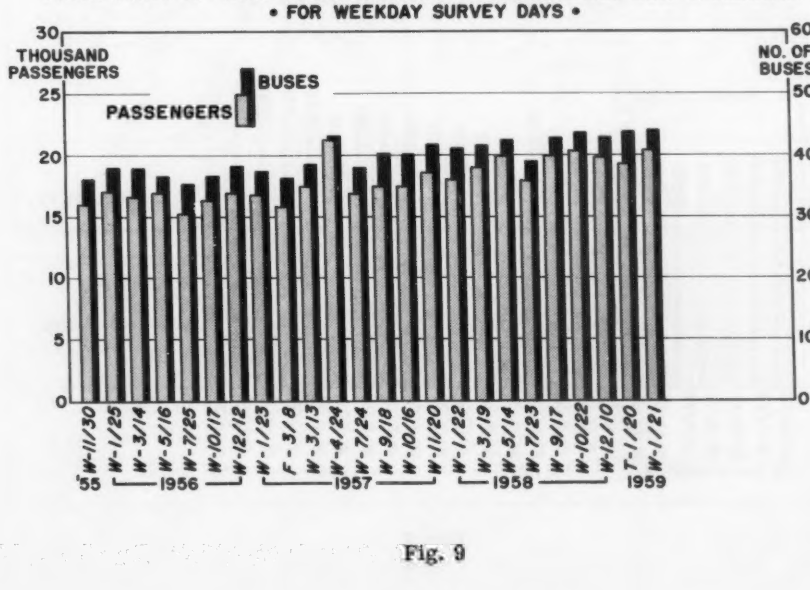

Fig. 9

employment and is also within easy connections with rapid transit subways and local franchise buses running along the avenues on which the Bus Terminal faces.

Figures often repeated have placed the rated passenger capacity of rail rapid transit at 40,000 persons an hour and then compared them with passenger capacities of buses rated at only 3,000 persons an hour. Rated hourly passenger capacities of franchise buses running along city streets, stopping and starting to pick up and discharge passengers within a CBD, are, of course, not to be compared with rail transit between suburban communities and the CBD. Such a comparison is not valid because the street buses function only as collectors and distributors of passengers (even rail passengers) within the CBD. Rated peak hourly passenger capacities of rail transit should, in fairness, be compared with interurban buses like those that use the Port Authority Bus Terminal in Manhattan, and that actually handle between 20,000 and 25,000 passengers in the rush hour.

At the origin ends of their trips, the interurban buses start out among New Jersey suburban communities and collect their passengers in the morning. When they approach the Lincoln Tunnel, they move along an approach expressway to the tunnel and then share a tunnel lane with autos to reach Manhattan. In the off hours, the lane that was shared by the buses is then used by autos and trucks. One highway or tunnel lane is thus in use for 24 hours a day for 365 days a year. A comparable railroad track, on the other hand, would be used largely for some 2 or 3 morning hours (and the other track for 2 or 3 afternoon hours) for only some 250 weekdays. Each track would be used for only about 750 out of a total of 8,760 hours in a year.

Fig. 10. Morning rush hour on April 24, 1959, showing buses on ramps leading to The Port of New York Authority's mid-Manhattan bus terminal.

A pair of expressway lanes allocated exclusively (or preferentially) for interurban buses in morning and afternoon rush hours and available for autos and trucks as well as buses in the remaining hours would thus be utilized far more intensively, in the course of a year, than would a pair of railroad tracks.

Mass transit by rail is at its best where it can serve communities located along the rail transit line like "beads on a string", and where the travel of the residents of these communities is concentrated at the destination and in a small area in a CBD, about half an hour to an hour away from homes, and within a few minutes walking or riding distance to important destinations in the CBD. Communities located too close to the CBD tend to slow down commuter rail service. Nearby rail commuters might better be handled by short haul interurban buses, and thus help speed up commuter rail service to more distant communities. Also a large CBD area which is beyond easy walking distances from rail terminals requires a fast mass distribution system within the CBD itself, for any mass transit, rail or bus, to be sufficiently attractive and thus to be heavily patronized.

In the NJ-NY Region existing rail mass transit has served the CBD best, but there its travel market has been declining, in part, because of greater employment opportunities elsewhere in the Region and in other parts of the CBD less convenient to New Jersey railroads' terminals. The rail mass transit that is available and that represents sunk capital is, of course, being used to a maximum where these railroads still give the best service. Nevertheless the passenger carrying operations of such carriers are in the red.

Today, capital investments in new systems of rail mass transit facilities, do not appear to be justified. Studies have invariably pointed to substantial

Fig. 11. Evening rush hour on April 24, 1959, showing buses on ramps leading to The Port of New York Authority's mid-Manhattan bus terminal.

deficits because such new proposed systems of rail mass transit would only satisfy largely only the weekday journey-to-work demand to and from the CBD. The weekday non-CBD travel, "reverse travel" and the expanding week-end leisure time travel demand would still have to be met by limited access highways. These limited access highways could also satisfy the journey-to-work demand with express buses and preferential or exclusive bus lanes, if required.

If communities wish to take advantage of the economies of existing mass transit on rails, where there is already sunk capital; if they wish to encourage use of mass transit and discourage auto travel on weekdays, particularly where all-day parking is involved, then the place to begin is with the journey-to-work linkages between residential and business areas. Communities must begin by planning and encouraging the redevelopment of sites of employment in areas where such existing mass transit could be made more attractive than the automobile. They must also actively help bring into being good mass transit by interurban bus via expressways, to newly developed sites of employment.

To achieve intensive use of mass transit, it is essential to plan for clusters of sites of heavy employment within small enough areas so that most employees would be within easy walking distances from mass transit stops to their places of employment. Yet such clusters of employment sites should be large enough to generate sufficient volumes of journey-to-work movements. Under those conditions, in certain instances, good mass transit might become economically feasible, and if so, could be brought into being where necessary and even expanded, if necessary.

Fig. 12. Port Authority Bus Terminal interior—November 7, 1952.

Fig. 13. Port Authority Bus Terminal motor stairs—November 1, 1957.

Fig. 14. Passenger waiting line and buses on the commuter level in The Port of New York Authority's mid-Manhattan bus terminal around 5:00 P.M. on April 24, 1959.

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

FACTUAL DATA FOR URBAN TRANSPORTATION PLANNING[a]

R. R. Bartelsmeyer[1]

ABSTRACT

The problems of urban transportation can, and very probably will, become enormously greater with the continuation of the present trends. Every piece of information that can possibly be obtained should be utilized to guide the thinking and planning for the future transportation systems. This paper outlines the information that is needed.

The great concern over the urban transportation problem is fully justified by the circumstances. More than two-thirds of the people of the United States live in cities and urban areas, and nearly all of the population increase in recent years has occurred within or immediately adjacent to urban places. Present predictions point to a national population possibly as high as 225,000,000 by 1975, and if present trends continue, the urban transportation problems can, and very probably will, become enormously greater.

The study of transportation is far less advanced than the study of most other engineering aspects and is perhaps a more difficult problem. The subject is cities and people and vehicles, and these cannot be controlled or experimented with in a laboratory. The study of transportation is a comparatively young field, as witnessed by the fact that the Institute of Traffic Engineers was founded in 1930, whereas the American Society of Civil Engineers was founded in 1852.

A complete revolution in transportation has occurred in the last few decades. In rural areas it has meant going from the horse and buggy to the automobile, while in cities it meant a change from mass transportation to the automobile.

Note: Discussion open until May 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2276 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. HW 4, December, 1959.

a. Presented at the May 1959 ASCE Convention in Cleveland, Ohio.

1. Chf. Highway Engr., Ill. Div. of Highways, Springfield, Ill.

This is progress, but with progress have come new problems. Since most of the larger cities were laid out prior to the advent of the automobile, they are faced with the necessity of redesigning, rebuilding, and adapting an old street and highway system to satisfy the demands of the new mode of transportation.

The original planners certainly cannot be criticized for these older street layouts which were adequate for their foreseeable future. Neither can the more recent planners be criticized for not having foreseen the tremendous increase that has occurred in traffic in the last 20 years. However, all of the highway engineers, highway administrators, and planners of today should be severely criticized if they do not make use of every piece of information they can possibly obtain to guide their thinking and planning for the future transportation system.

What then is the proper approach to urban transportation planning and what are the various fields of information that are needed?

The approach to the Study of Urban Transportation will depend largely on the size of the place. The factual data needed for an urban place of 50,000 to 100,000 population is considerable, but generally it need not be nearly as all-inclusive as for a larger place of a million or more population.

The needs of a smaller urban place may well be analyzed from the results of two or three special studies, as for example an origin and destination study, a land use study, and a parking study. Each special study is designed to obtain information on one particular aspect of transportation.

The transportation system of a large metropolitan area is so great and so complex that information on all aspects of transportation must be obtained to properly coordinate and plan the development of each aspect as the area grows. To better illustrate just what this means, the work of the Chicago Area Transportation Study will be used as an example.

The survey techniques which were utilized by the Chicago Area Transportation Study are part of a stream of constantly improving techniques which have been developed in origin-destination traffic surveys in over one hundred cities in the United States in the past fifteen years. Such censuses and surveys, however, are but a means to an end. Like mining, they merely provide the raw material which to be made useful, must be processed and refined into a finished product. The facts which are gathered, therefore, must be precisely those which will be most useful in preparing the finished product. Data gathering is so expensive and time consuming that indiscriminate collection of facts can be most wasteful, and can cause the technician to lose sight of his real goal, the preparation of a transportation plan. The focus of this paper will be on the kinds of facts necessary for sound planning.

The organization of the Chicago Area Transportation Study, the largest of its kind ever attempted, was started in the fall of 1955. Four governmental units participated in its organization, and in its cost,—the Federal Bureau of Public Roads, the Illinois Division of Highways, the County of Cook, and the City of Chicago. A Policy Committee comprised of four members—one from each participating agency—is the governing body which controls the general policies, but the Illinois Division of Highways administers the work through the Director of the Study.

The purpose for establishing the Chicago Area Transportation Study was to develop a transportation plan for the Chicago Area for a long-range (25-year) period. This transportation plan was to be comprehensive in these respects:

(a) It was not to be for any single political jurisdiction, but for the functioning urban area of Chicago, (excluding Northern Lake County, Indiana);
(b) It was not for highways alone, but for all forms of person and vehicular traffic (except railroad freight, long haul rail passengers, and air travel);
(c) It was not limited to superficial examination and projection of trends, but it sought to obtain the most fundamental explanations for the causes of the generation and distribution of travel in an urban area; and
(d) It sought to integrate the work of a variety of specialists in urban transportation and related fields.

The valuable data which have been gathered will not disappear, however, when the reports are completed. A continuation of this work has been approved by the Study's Policy Committee. As the present organization tapers off, the permanent organization will retain a large proportion of its staff, and will have the responsibilities of maintaining data, supplying answers to specific short- and long-range planning questions posed by the sponsoring agencies, and conducting basic research.

The data required for the Chicago Metropolitan Area are divided into three categories:

(a) an inventory of travel,
(b) an inventory of land use, and
(c) an inventory of transportation facilities.

This inventory of travel contains information on the origin and destination of each trip (coded to a Cartesian coordinate system), the trip purpose, the land use at origin and destination, mode of travel, time, travel time, parking, route of travel, and other pertinent data.

The travel census was designed to sample every possible type of person and vehicle travel made within or through the Study area, accurately, and with economy. All trips were divided into two classes: those made by persons and by commercial vehicles who live or are registered within the Study area, and those made by persons and commercial vehicles from outside the Study area. The former trips were sampled by the internal surveys, and the latter by the external (roadside) surveys. Where overlapping occurred (as when a resident made a trip from his own home to a destination outside the Study area) the duplicate record of this trip was eliminated in the data-processing stage. Walking trips and trips by mass transportation as well as trips by motor vehicle were included in the study.

The second of the major inventories—the land use inventory—surveyed both land area and floor area. The land area survey, which measured the amount of land in each of ten categories of land use, has been completed for the 1,200 square mile Study Area and for the northern part of Lake County, Indiana. The floor area survey was only conducted for 300 square miles which had Sanborn map coverage, but this included all of the City of Chicago. The floor area survey measured floor area within 88 different categories of establishment types. These 88 categories are reconcilable on the first digit to the 10 land use categories. This land use survey is actually the largest as well as the most detailed such survey ever conducted.

The third major survey was the inventory of transportation facilities. This inventory coded 2,700 intersections and 4,700 routes between intersections in the 1,200 square mile Study Area. Each intersection was described by its

geographic location, the links or route sections entering it, its signalization, its type, and other features. The route sections, or links, between intersections were coded by length, by the intersections served, by width, and by route type, (whether arterial, boulevard, or expressway). Intersections and links of mass transportation facilities were included in the survey. With these facts it became possible, either manually or by machine, to proceed from intersection to intersection through the entire network of transportation facilities, by any mode of travel, tracing and remembering the links which had been used. The Study included an inventory of the mass transportation facilities—their actual use and capacity.

The gathering of all this data is a tremendous task in a large metropolitan area, but it is essential that highway planners learn to understand just what motivates people to travel and why, before they can become reasonably proficient in forecasting travel. The relationship between land use and trip generation must be determined to enable planners to predict how many trips future land use will generate.

Forecasting trip generation, estimating trip distribution, and making assignments of future traffic volumes to transportation networks are the necessary processes for forecasting traffic, and the trip data with land use data will play a significant role in providing the constants and exponents, the formulae and the relationship needed for accurate predictions of traffic.

In a large metropolitan area where mass transportation still plays an important role, a study of travel on busses, street cars, rapid transit, and commuter trains is essential. It is obviously necessary to estimate the future passenger volumes on mass transportation systems, as well as traffic volumes on the street systems. All of this is essential to establish a proper balance between travel by private motor vehicles and travel by mass transportation.

Another problem is the prediction of truck traffic and the prediction of external traffic both of which require detailed study of volumes, characteristics, and trends to permit intelligent projection to the future.

Similar transportation studies have been made in 15 of the larger urban places in Illinois. These ranged in size from the second largest city in Illinois—Peoria—to Carbondale with a population of 14,000. One of these studies covered an area about 30 miles long and 15 miles wide extending through two counties and including East St. Louis, Alton, and the many other municipalities in that area.

A traffic origin and destination study and a land use study have always been included down to and including the smallest of such urban places studied. A study of existing street and highway facilities has also been included in every case. However, in places of less than 50,000 population, the mass transportation study has been omitted because it usually plays a minor role in the whole transportation problem.

Parking studies have not been included in the urban transportation surveys made by the Illinois Division of Highways, but cities have been urged to make them and many have on their own initiative and at their own expense.

Recognizing the urgency of solving the urban transportation problems, six national organizations of public officials formed the National Committee on Urban Transportation in 1954. The first objective of this committee was to develop a manual of methods and procedures by which cities could undertake a complete fact gathering program to help evaluate deficiencies, project future needs, and formulate a more realistic transportation policy. A basic guide

entitled "Better Transportation for Your City" and 15 detailed procedure manuals have been developed through the efforts of this committee.

Specific study areas covered and recommended are:

1. Laws, Ordinances, and Transportation Administration.
2. Appraisal of the level of traffic service including parking, travel time, volume counting, capacity.
3. Inventory of traffic control devices.
4. Better accident reporting and records.
5. Physical inventory of the street system.
6. Origin and destination survey.
7. Land use survey.
8. Appraisal of transit service.

The guide manual was prepared to help cities do a better job of transportation planning through systematic collection and analysis of basic facts.

The day is past when the highway engineer can confine his thoughts and interests to the physical aspect of the highway. He must realize that the end objective is not to build roads, but to serve people. This means that the engineer must become conversant with the complex activity called urban transportation, and it is only through these fact-finding studies that he can attain that knowledge.

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Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

SPACING OF INTERCHANGES ON FREEWAYS IN URBAN AREAS[a]

Jack E. Leisch,[1] M. ASCE

SYNOPSIS

Location and spacing of interchanges on freeways has a pronounced effect upon the transportation system of a city. Widely spaced interchanges do not provide the needed service; on the other hand, too many interchanges result in loss of speed and capacity. Bases for spacing of interchanges, including schemes for increasing operational efficiency, are presented.

INTRODUCTION

The ability of a freeway to carry traffic effectively depends to a great degree on the location and spacing of its interchanges. Widely spaced interchanges do not provide the needed service or develop the potential use of the facility. Too many interchanges, on the other hand, result in friction, inefficiency, and loss of speed and capacity. What, then, is the right spacing of interchanges on urban freeways?

To answer the question, certain key factors should be examined: external factors such as size of city, type of area, and street pattern; and internal factors, such as geometric features and operational characteristics of the highway. Knowing these factors, general minimum spacing can be prescribed, and arrangements permitting closer than general minimum spacing can be developed.

External Factors Influencing Location and Spacing

The street pattern as well as the arrangement and frequency of arterial streets crossed by the freeway have a definite influence on the location and

Note: Discussion open until May 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2277 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. HW 4, December, 1959.

a. Presented at the June 1958 ASCE Convention in Portland, Oregon.

1. Chf. Highway Engr., De Leuw, Cather & Co.

spacing of interchanges. Need of frequent ramp connections is minimized when the street pattern is regular—for example, the familiar grid-iron. This is especially true when the freeway parallels one set of streets and has continuous frontage roads. A hetrogeneous or a disconnected pattern of streets together with an irregular arterial street system, on the other hand, tend to require close spacing of interchanges.

The location and frequency of freeway access connections vary somewhat with the size of the city as well as with topography and land use. Large commercial and industrial areas, because of the magnitude of traffic generation, call for numerous points of ingress and egress. This need obviously diminishes as the freeway passes outward from the central business district or away from areas of intensive development.

Interchanges are needed at focal points of high traffic generation such as large industrial plants, airports, and stadia or parks for sports events. Such interchanges, invariably of the directional type, need to be fitted into the normal sequence of interchanges. High traffic concentrations also occur where freeways merge or intersect. These points, too, call for elaborate interchange arrangements. The location of these major interchanges frequently affects the location of the freeways themselves as well as that of subsidiary interchanges. Large volumes of vehicles maneuver for position to leave or enter the freeway at these interchanges. Consideration must be given to proper signing and to the need for minimizing weaving of traffic. For these reasons, the distance from a major interchange to the next regular interchange should be greater than the spacing in a series of regular interchanges.

Internal Factors Influencing Location and Spacing

Operational characteristics of a freeway are governed largely by its geometric features. The more traffic that is imposed upon a facility the more difficult and complex becomes its operation, particularly in conjunction with interchanges. Part of the problem can be overcome by expanding the facility laterally, i.e., by adding width or lanes. But, much of the problem must be solved by expanding the facility longitudinally, i.e., by increasing lengths of maneuver areas and weaving sections. These play an important role in the spacing of interchanges.

The most troublesome feature of operation in conjunction with interchanges is that of weaving. This is produced when two traffic streams, moving in the same general direction cross each other by merging and diverging maneuvers. Weaving is inherent to some types of interchanges, particularly the cloverleaf, but it is often produced by other types when they are closely spaced. Positive control of weaving through the spacing of ramp entrances and exits is discussed later.

Distances between interchanges also are affected by the necessary directional signing. There can be too many signs in a given length of highway. Drivers must have sufficiently long maneuver areas to read, comprehend, and act on the messages imparted. Thus, signing is a definite consideration in the spacing of interchanges.

Spacing of Interchanges on Existing Freeways

Having discussed factors influencing the location and spacing of interchanges, it is of interest to examine actual spacing on typical urban freeways.

Table 1 shows such information for a few examples. While this small sample may not be representative, it is at least indicative.

Table 1

Approximate Spacing** of Interchanges on Typical Urban Freeways

Location	Facility	Approx. Length In Miles	Average Spacing Between Interchanges—Miles
Washington and Vicinity	Pentagon Network	4.3	0.35
	Shirley Highway	2.7	0.90*
Chicago and Vicinity	Congress Street Expressway	6.0	0.75
	Edens Expressway	13.0	1.30*
	Calumet & Tri-State Expressways	20.0	1.55*
Atlanta	Expressway (Route 295)	4.5	0.65
Detroit and Vicinity	Edsel Ford Expressway	5.3	0.55
	John C. Lodge Expressway	4.5	0.55
	Detroit Industrial Expressway	11.5	1.65*
New York and Vicinity	Parkways in Queens	18.0	1.00*
	Shore & Southern Parkways	22.5	1.70*
	New Jersey Route 17	7.3	0.90*
San Francisco	Bayshore Freeway	5.5	0.65
Philadelphia	Schuylkill Expressway	13.0	2.10*

* - Suburban

** - Distance between cross streets or intersecting highways to which ramps are connected.

The approximate range and average of interchange spacing are as follows:

Urban Areas:

Range—0.35 to 0.75 miles (1800 to 4000 feet)
Average—0.60 miles (3200 feet)

Suburban Areas:

Range—0.90 - 2.10 miles (4800 to 11,000 feet)
Average—1.50 miles (8000 feet)

Spacing of Interchanges Based on Operational Features

The above values compare generally with the spacing of interchanges predicated on traffic requirements; that is, operationally there is a need for

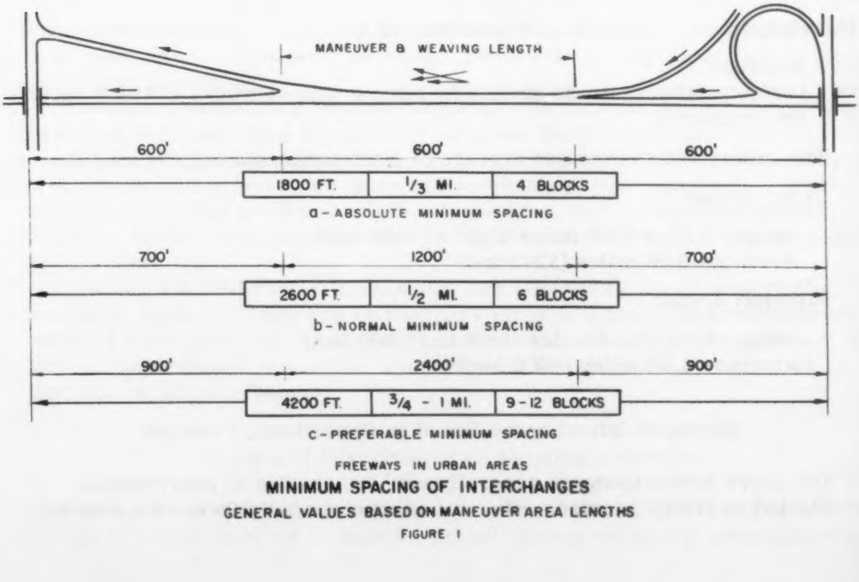
certain lengths of maneuver and weaving sections between successive interchanges. These lengths, of course, vary with the volume and pattern of through, entering and leaving traffic.

The absolute minimum spacing of interchanges may be based on a combination minimum maneuver and weaving length of 600 feet. See Fig. 1-a. An additional length of 600 feet on each side of this weaving section is estimated to be the minimum for an entering ramp on one end and an exiting ramp on the other end. The resulting spacing of 1800 feet is the absolute minimum which may be considered in urban areas involving light to intermediate weaving volumes. This spacing is equivalent to approximately 1/3 mile.

Normally the minimum weaving section between an entering and exiting ramp should be around 1200 feet. This is equivalent to two maneuver areas joined end to end, i.e., a 600-foot merging maneuver length and a 600-foot diverging maneuver length butted together. Relatively heavy traffic can be accommodated, including weaving volumes upwards of 1500 vph. Assuming a length of 700 feet for each of the adjoining ramps, a minimum spacing of 2600 feet or about 1/2 mile is indicated, as shown in Fig. 1-b.

A preferable minimum spacing may be based on twice the normal length of maneuver areas, or a distance of 2400 feet between entering and exiting ramps, resulting in a span of about 4200 feet, or 3/4 to one mile. This is thought of usually as a favorable spacing in built-up areas.

The above distances of 1800, 2600 and 4200 feet are general guides of what may be considered the absolute, normal, and preferable minimums for spacing of interchanges on urban freeways. Another set of values, based specifically on the volume and pattern of interchanging traffic may be more appropriately used in design as criteria for spacing of interchanges. These values, as developed in Fig. 2, are predicated directly on the effects of weaving traffic ($w_1 + w_2$)—entering traffic c-b maneuvering across leaving traffic a-d. Effect on operation of given volumes of weaving traffic varies with the length of weaving section e-f. Guide values are resolved as shown in Fig. 2



FREEWAYS IN URBAN AREAS
MINIMUM SPACING OF INTERCHANGES
GENERAL VALUES BASED ON MANEUVER AREA LENGTHS
FIGURE 1

by considering weaving lengths over the entire range of weaving possibilities and coupling these with lengths in the range of 650 to 1100 feet for development of ramps on each end.

Spacings in the upper part of the tabulation, referred to as the low limit, are predicated on minimum weaving distances required to maintain normal operating speeds on a freeway.* Values in the lower part, designating high limits of spacing, are based on distances between entering and exiting ramps which are sufficient to place the traffic maneuvers out of the realm of weaving.** The above information, including an intermediate set of values, is also depicted in Fig. 3 in the form of a design chart. Application of these criteria may be as follows:

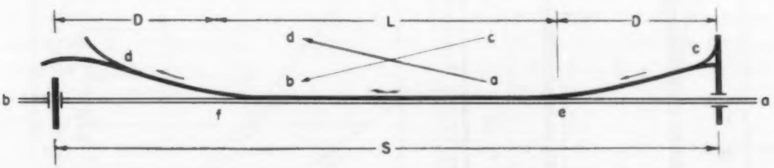
Curve C, low minimum spacing, should be considered as a minimum control in highly built-up districts between ordinary interchanges, such as diamond and parclo*** type arrangements.

Curve B, high minimum spacing, may be taken as preferable minimum values in areas of concentrated urban development, and generally as the minimum values in suburban areas. Spacings shown by this curve may also be used appropriately as the minimum between a major interchange—directional type at the intersection with another freeway—and any ordinary interchange. The use of Curve B values as a minimum in this case is believed to be essential. More than normal distance is required to satisfy the complexity of maneuvers taking place in conjunction with major exits and entrances, and

*Relation shown for average running speed of 35 mph in AASHO "Policy on Arterial Highways in Urban Areas," 1957—Page 492.

**Tabulation in AASHO "Policy on Arterial Highways in Urban Areas," 1957—Page 493.

***Partial cloverleaf.



LIMITS OF SPACING	$(W_1 + W_2)$ weaving volume vph	D length allowed for each ramp feet	L* length of weaving section feet	S interchange spacing feet
LOW LIMIT (minimum)	1000 1500 2000 2500	650 850 1000 1100	500 900 1400 2000	1800 2600 3400 4200
HIGH LIMIT (desirable)	1000 1500 2000 2500	850 1000 1000 1000	2300 4000 6000 8000	4200 6000 8000 10,000

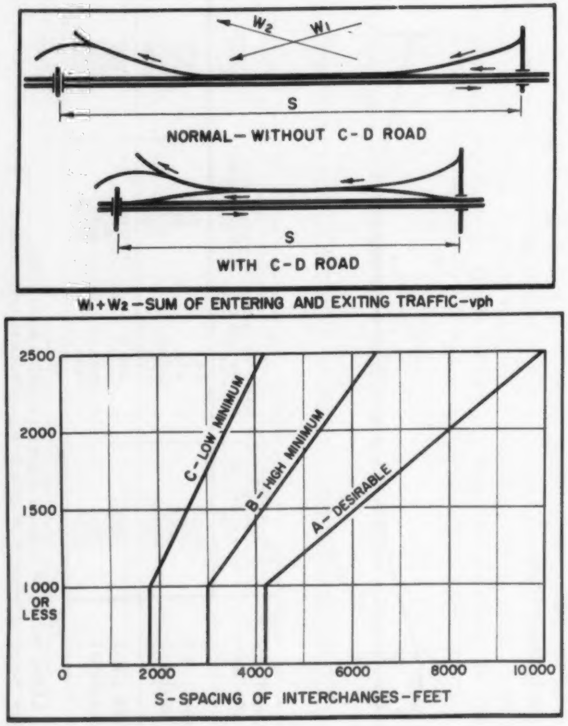
*From AASHO Policy on Arterial Highways in Urban Areas, 1957:
Minimum based on relations for 35 mph average running speed, p. 492;
Desirable based on distances at which traffic maneuvers pass out of realm of weaving, p. 493.

FREEWAYS IN URBAN AREAS

LIMITS OF INTERCHANGE SPACING

BASED ON WEAVING MANEUVERS

FIGURE 2



APPLICATION

URBAN

CURVE C - MINIMUM
CURVE B - PREFERABLE MINIMUM FOR NORMAL INTERCHANGES MINIMUM IN CONJUNCTION WITH MAJOR (DIRECTIONAL) INTERCHANGES
CURVE A - DESIRABLE; SHOULD BE STRIVED FOR WHERE FEASIBLE

SUBURBAN

CURVE C - NOT APPLICABLE EXCEPT WITH C-D ROAD
CURVE B - MINIMUM
CURVE A - PREFERABLE MINIMUM

WITH C-D ROAD

CURVE C - DESIRABLE IN URBAN AREAS; PREFERABLE MINIMUM IN SUBURBAN AREAS
CURVES B AND A - DESIRABLE IN SUBURBAN AREAS AND IN URBAN AREAS WITH INTERMEDIATE LOCAL RAMPS

FREEWAYS IN URBAN AREAS

DESIGN CHART FOR SPACING OF INTERCHANGES

AS CONTROLLED BY OPERATIONAL FEATURES

FIGURE 3

greater distances are required for advance overhead and other directional signing.

Desirable spacing, Curve A, should be strived for where feasible. It provides distances at which the disturbing characteristics of an entrance ramp followed by an exit ramp are substantially removed. These values should be considered as preferable minimums in suburban areas.

Arrangements Permitting Closer Than Minimum Spacing

In suburban and outlying areas, spacing of interchanges to produce favorable operating characteristics can be accomplished without difficulty in most cases. In areas of concentrated urban development, however, proper spacing usually is difficult of attainment because of traffic demand for frequent access. This comes about as a result of large volumes of traffic generated within a relatively small area, as in the vicinity of the central business district. There is a limit to the amount of traffic which can be accommodated per ramp; consequently, numerous ramps often are called for on freeways serving downtown areas. Sometimes the traffic demand for ingress and egress is of such magnitude that, if fully accommodated, the free-flowing characteristics of a freeway would be destroyed by too close spacing of ramps.

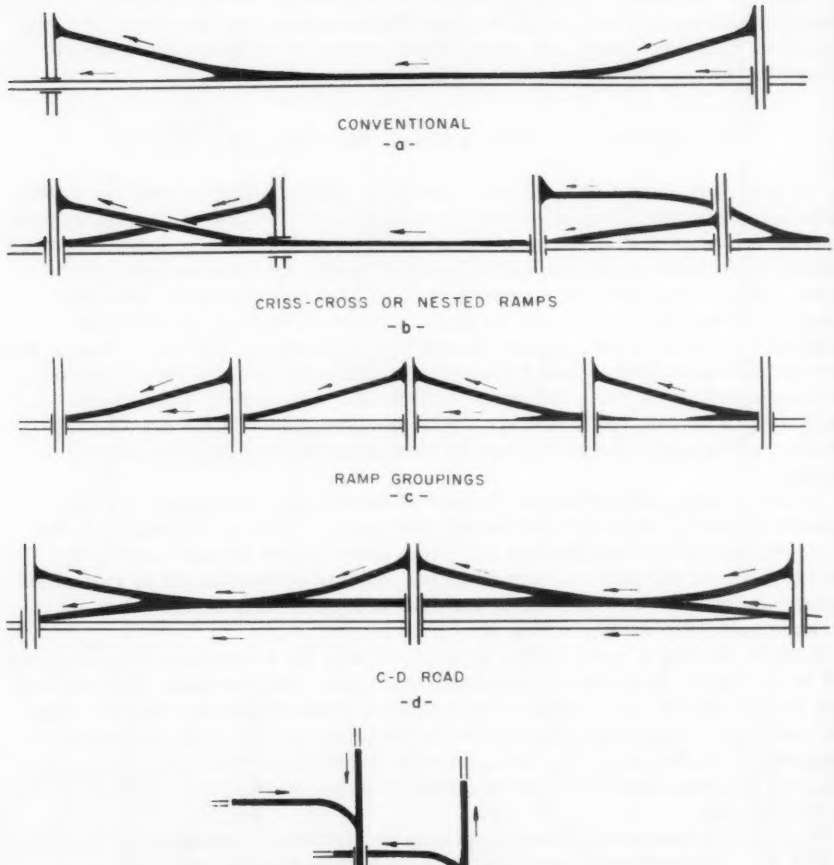
This presents a problem on the part of the designer to satisfy the two classes of traffic—through traffic and that terminating or originating in the business district. Each hinders the other under heavy volume conditions. To satisfy both, it becomes necessary to use special arrangements of ramps permitting more exits and entrances than can conventionally be provided. Such arrangements are shown in Fig. 4.

Ramps serving a large traffic generator, such as a downtown district, need not be thought of as parts of individual or distinct interchanges. Instead, they may be considered as a series of exit and entrance ramps serving the area. For example, ramp frequency can be increased by criss-cross or nested arrangements as shown in Fig. 4-b. Normal sequence of exits and entrances of Fig. 4-a is maintained here, but a greater number of ramps is made possible by the overlap.

Increase in number of ramps also may be effected by grouping as indicated in Fig. 4-c. Two or more successive exits followed by two or more successive entrances obviously permit the use of a greater number of ramps in a given length of highway than by the usual method of alternating entrance and exit ramps shown in Fig. 4-a.

Another method by which the frequency of connecting ramps may be increased is by the use of collector-distributor roads, illustrated in Fig. 4-d. Because ramps connect to the C-D road rather than to the through traveled way, their number may be increased due to shorter maneuver and weaving area lengths required. But, what is more important is that through and terminating vehicles are separated, permitting free-flowing characteristics to be maintained on the freeway proper.

Large volumes of traffic also may be discharged and collected along a relatively short length of freeway by the use of a lateral distributor as shown in Fig. 4-e. The distributor is a lateral extension of the freeway, in effect, coupled with a series of ramps connecting with the street system. By this arrangement, one major exit and entrance along the freeway can accommodate numerous ramps.



FREEWAYS IN URBAN AREAS

ARRANGEMENTS TO INCREASE FREQUENCY OF RAMPS

FIGURE 4

The extent to which ramp frequency may be increased by these devices or combinations thereof is illustrated in Fig. 5. The numbers at the right show the ramp frequency index, which is the ratio of the number of ramps per mile on a given arrangement to the number of ramps per mile on the conventional or basic arrangement (a). The arrangement (b) with criss-cross or nested ramps has an index of 1.2, or an increase of 20 per cent in the number of ramps over arrangement (a). Plan (c) with ramp groupings and plan (d) with a C-D road both have a ramp frequency index of 1.3. Arrangement (e), combining nested and groupings of ramps, increases the number of ramps by 50 per cent; arrangement (f), combining a C-D road and ramp groupings, increases the number of ramps by 70 per cent. Using lateral distributors in series, plan (g), the number of ramps may be twice that of the conventional plan (a).

These various arrangements are useful devices for increasing the over-all ability of a freeway to discharge and collect traffic in a relatively short distance without decreasing the capacity or the effectiveness of the freeway.

Distribution Systems

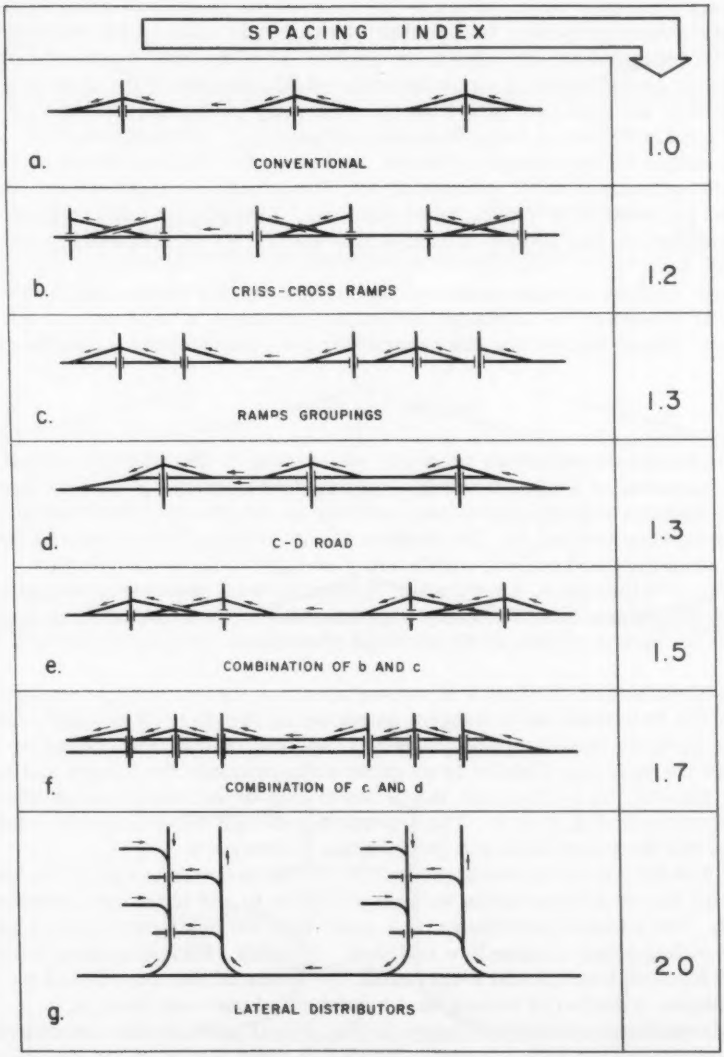
To serve downtown areas properly, some form of distribution system usually is essential in conjunction with freeway development. A well-designed system assures efficient operation, not only on the freeway itself but on the surface streets serving it. The devices for increasing the ability of a freeway to discharge and collect traffic are also applicable to distribution systems. Furthermore, a network of feeder streets, preferably providing one-way operation, is a necessary adjunct. These two features are combined to make up various forms of distribution systems as illustrated in Figs. 6, 7 and 8.

A single freeway skirting a downtown area may be served by arterial cross streets and individual interchanges, as shown in Fig. 6-a. Sometimes interchanges must be closely spaced, however, and the traffic terminating or originating in the business district is so great as to overload the ramps and connecting streets. In such cases, the problem may be solved by one of the other arrangements in Fig. 6 or 7. The appropriate design depends on the size and shape of the downtown area and the location of freeways.

Fig. 6-b diagrams one arrangement in conjunction with a single freeway which can handle a tremendous volume of traffic to and from the business district. The parallel distributor is a controlled access facility, much like a service siding along a main-line railroad. A highly efficient system is developed for both through and local traffic by means of two directional Y-interchanges, a series of ramps, and a network of one-way streets.

The transverse distributor shown in Fig. 6-c is suitable for a downtown area of nominal size with a freeway located at right angles to its long dimension. The distributor is a freeway spur of any length required to handle the discharge and pick-up of traffic. Ramps connect with a series of one-way streets into and out of the business district.

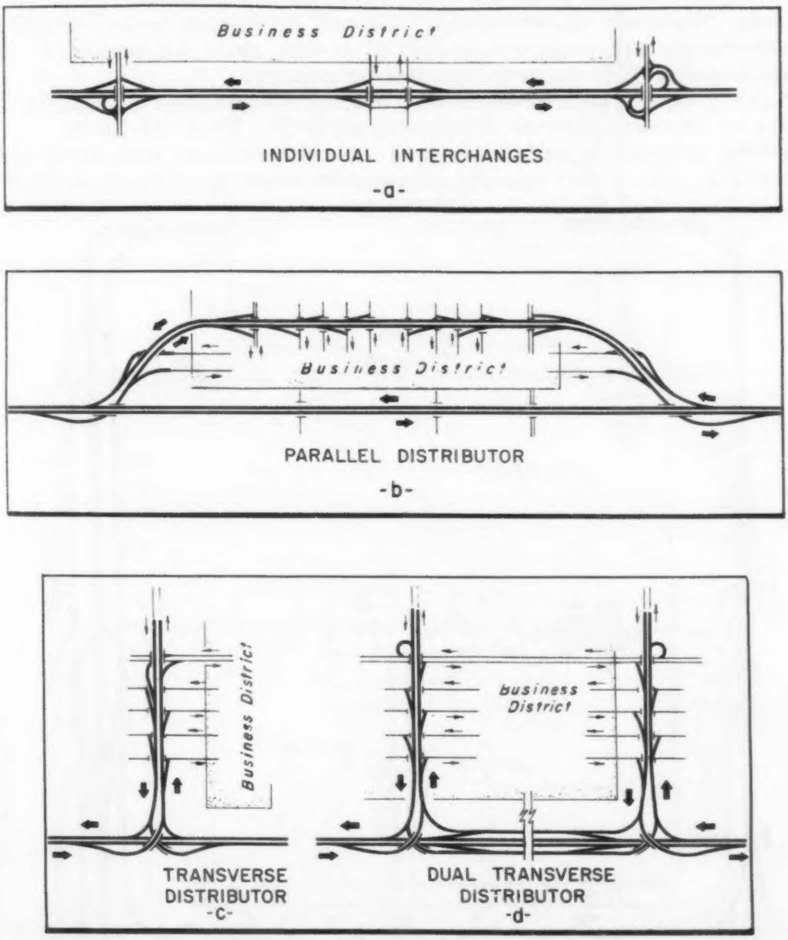
For larger downtown areas, two such transverse distributors may be utilized as indicated in Fig.. 6-d. This provides a highly flexible and efficient arrangement. The arterial street at the top of the diagram completes a circumferential with only one leg without control of access. C-D roads may be used along the freeway between the major interchanges, as shown, to alleviate weaving and to permit through traffic to operate freely.



FREEWAYS IN URBAN AREAS

COMPARISON OF ARRANGEMENT TO INCREASE RAMP FREQUENCY

FIGURE 5



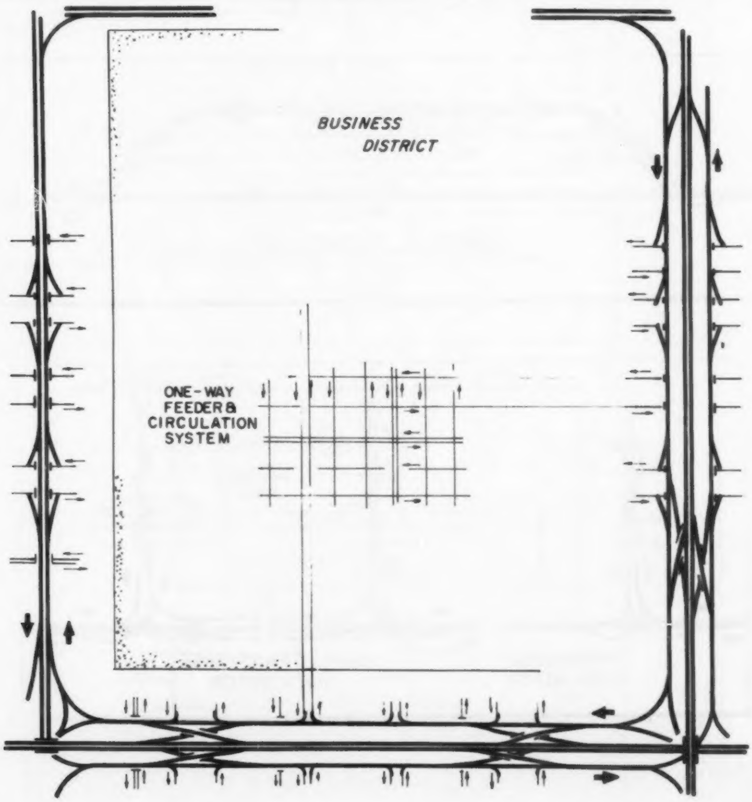
FREEWAYS IN URBAN AREAS

DISTRIBUTION SYSTEMS—DIAGRAMMATIC

FIGURE 6

In large metropolitan areas, the arterial system of highways generally calls for a belt freeway around the central business district. The two-way inner loop permits any point within to be reached with minimum travel distance. Necessary adjuncts to this elaborate distribution system include a one-way feeder and circulation network of streets, and arrangements of ramps to permit high discharge and pick-up capacity.

Radial freeways in large cities often overlap the inner belt highway, resulting in large accumulation and weaving of traffic. Future traffic is frequently estimated at daily volumes of 100 to 150 thousand vehicles on parts of such a facility. These volumes often call for unwieldy widths of pavements

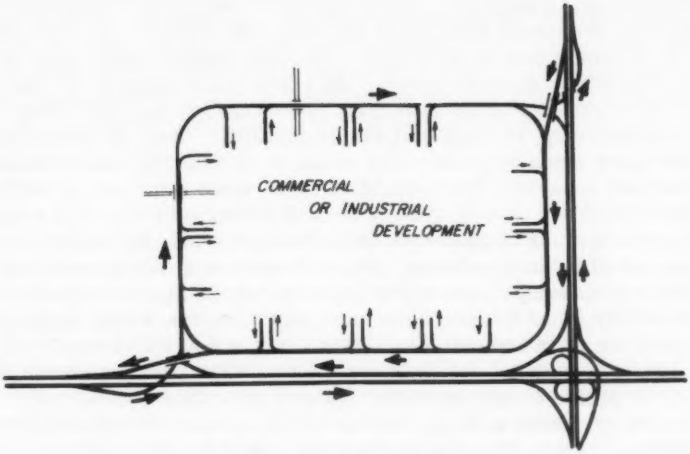


DISTRIBUTION SYSTEMS—DIAGRAMMATIC

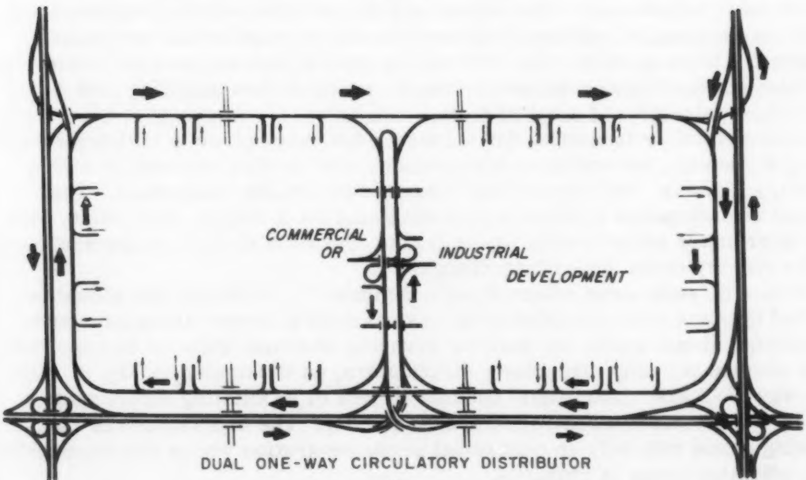
INNER CIRCUMFERENTIAL HIGHWAY

DIAGRAMMATIC

FIGURE 7



ONE-WAY CIRCULATORY DISTRIBUTOR
-a-



DUAL ONE-WAY CIRCULATORY DISTRIBUTOR
-b-

FREEWAYS IN URBAN AREAS

DISTRIBUTION SYSTEMS-DIAGRAMMATIC

OUTLYING COMMERCIAL AREAS

FIGURE 8

and unworkable weaving sections if the freeway is designed as one pair of roadways.

In such instances, however, the problem can be solved on a single facility if the troublesome weaving maneuvers are removed from the through lanes. This may be accomplished by providing C-D roads continuously on all or parts of the inner loop highway between the major interchanges. As shown on the bottom and right legs of the loop, Fig. 7, the through lanes are free of the disturbance of entering, leaving, and weaving traffic. Thus, by the use of C-D roads, the inner lanes of the freeway retain their express characteristics of high speed and capacity. The total of 12 or 14 lanes required on parts of the circumferential can thus be readily divided among four traveled ways.

Without such doubling of roadways on critical portions, the system is apt to be thrown out of balance, causing serious breakdowns during peak hours. In large cities, for example, the radial highways on the approach to the inner belt are invariably 6 and 8 lanes wide. For short lengths, where auxiliary lanes are used for exits and entrances, they become 8 and 10 lanes wide. This normally is considered the limit for the roadways constituting the freeway proper. At least one additional lane in each direction is often called for, however, by the overlapping of movements of the converging radial freeways and the additional ramps required on the belt. Because of the rule-of-thumb limit on maximum number of lanes, this additional width, although needed, is sometimes not provided. The omission is rationalized on the basis that the overloading occurs only a few hours each day and that a fully adequate design is not economically justified. Failure to use C-D roads where an unusual number of lanes is called for, however, is poor design and may be looked upon as false economy, since the result may be costly delays to traffic and, ultimately, construction of a relief road.

Commercial or industrial development often takes place in outlying areas along a freeway, especially at intersections with another freeway or with a primary highway. Such areas may become huge traffic generators. They should be anticipated in planning and designing the freeway. Otherwise, they can later cause serious difficulty in traffic operation if local ramps are added in the vicinity of the major interchanges.

Properly, such large commercial and industrial developments should be served by some form of distribution system such as those discussed above. In outlying areas, unlike the built-up districts of cities, there is an opportunity to develop one-way circulatory distributors, as illustrated in Fig. 8. The one-way clockwise distributor, because of lack of an existing street system, can be readily made a controlled access facility. The highway can be built at existing grade with only an occasional grade separation where interconnection with adjoining areas is required.

In Fig. 8-a, the two interchanges serving the area are properly spaced from the major interchange. The interchanges with the distribution system are simple and direct as a result of the one-way clockwise movement on the distributor. Although the system provides high capacity and considerable flexibility of movement, it has little adverse effect on through traffic. Some movements into and out of the area necessitate longer travel distance than would be required on a two-way circulatory distributor; but, if the latter were provided as a controlled access facility, it would likely be prohibitively costly. A two-way circulatory distributor without control of access also would be less desirable than the plans of Fig. 8-a and 8-b because of at-grade conflicts and generally less efficient operation.

The builders of such a commercial or industrial development should ordinarily provide the traffic distribution system as part of the project. Generally not more than one such large area should be permitted to develop at the intersection of two freeways. If positioned in diagonally opposite quadrants, however, two such areas may be adequately served. The general plans of Figs. 8-a and 8-b are also applicable to development of future neighborhood units in outlying areas. These plans can be readily adapted to stage construction, spreading the cost over a long period of time.

CONCLUSION

Location and spacing of interchanges on freeways has a pronounced effect upon the transportation system of a city. Interchanges widely spaced do not provide the needed service or develop the potential use of the arterial system of highways. Too many interchanges on the other hand, lead to inefficient operation and tend to destroy the free-flowing characteristics of controlled access facilities.

It is desirable to space freeway interchanges widely when considering land use and operational factors. In order to fit into the pattern of existing or proposed developments, however, interchanges frequently must be spaced closer than otherwise deemed appropriate. This is especially true in providing connections between freeways and the distribution networks serving central business districts or other heavy traffic generators.

This paper offers certain guides to freeway designers, but in so doing, it barely introduces a very important subject. There is an urgent need for highway, traffic, and planning engineers to combine their efforts in conducting appropriate research on this vital phase of planning and design of urban freeways.

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Journal of the

HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

MODERN CURVILINEAR HIGHWAY LOCATION AND DESIGN

F. W. Cron,[1] M. ASCE

ABSTRACT

Good highway locations are tailored to fit the expected traffic and the terrain. To achieve satisfactory appearance and to avoid monotony, excessive property damage and high construction cost the locator should have freedom of maneuver, using long sweeping curves and tangents in combination rather than excessively long tangents, at the same time avoiding excessive curvature. The two roadways of a divided highway need not be parallel to each other in either alignment or grade. Modern locations are easiest to achieve when they are made by projecting on accurate topography, rather than by direct location in the field; and when the tools of modern technology, such as photogrammetry, are fully utilized.

The most important period in the life of a highway is the period of planning, location and design that precedes the moving of the first shovelful of dirt. If the road is built in the wrong place, or is poorly located or designed, little or nothing can be done during construction or maintenance to improve it; its defects are built-in, immovable, incurably permanent.

Good highway locations do not come about by accident; neither can they be mass-produced by the mile like newsprint or baling wire. A good highway is tailored to fit not only the traffic it must carry, but also the ever-changing wrinkled surface of the earth, and this requires considerable engineering effort by trained men as well as a certain minimum of time for investigation and study. If the location process is hurried or skimped, grave mistakes can be made which may greatly increase construction cost, annual maintenance expense and operating cost to the public.

Note: Discussion open until May 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2278 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. HW 4, December, 1959.

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Highways are built to serve both traffic and the land, but some highways partake more of one of these aspects of service than the other. Generally, modern roads built primarily for traffic service are multiple-lane high-capacity high-speed roads with control of access, while land service roads are of lower standard and without access control. This distinction has much to do with the location of the highway, as will be seen later in this discussion.

The determination of the general location for a highway is a problem of economics and politics. The function of highway engineering at this stage is to supply factual information upon which to base sound economic and political decisions, and modern research has developed reasonably reliable techniques for gathering traffic data and information about trends in traffic and economic development, and for interpreting these data. It is now possible to predict with fair accuracy where there is need for a road and about how much traffic it should be designed to carry. This forecast in effect sketches a "traffic corridor," to some extent independent of topography, within which any road serving the corridor must lie. Where very large volumes of traffic exist, as on the approaches to large cities two or more highways or streets may be required to serve the traffic in any given corridor. Interchanges with other important highways, points of heavy concentration of industry, or even important recreational areas which generate large volumes of traffic are examples of "controls" which determine the location of traffic corridors.

For rural roads intermediate towns and cities might be controls for the traffic corridor. The corridor would not necessarily follow the shortest and most direct route between the termini; in fact it would rarely do so, except in uninhabited or undeveloped country, and even here the potentialities for future development might properly draw the route away from the most direct line.

Between the principal control points delineating the traffic corridor there are others imposed by topography or by the works of man. It is these which concern the highway locator, and to distinguish them from economic or traffic controls, we might call them "terrain controls." The most important terrain controls either fix the location in particular places, or, negatively, deny the locator the use of certain areas. An example of the former would be an unusually favorable mountain pass, while a negative control might be a railroad yard or an area of swampy unstable soil. The economic controls and the terrain controls together determine the "route band" within which the locator must find his detailed location. Between the major terrain controls there are many choices of location, each influenced by differences in the contour of the land, its culture, or its ownership. Inevitably, every location is a compromise for seldom do the ideal conditions for construction economy, minimum disturbance of land ownership, favorable operating characteristics and satisfactory geometric appearance occur together. The quality of the final location is dependent upon the skill, experience and judgment of the locator, and the emphasis he places upon the various circumstances which influence the location.

Actually, location is an art, not a science, and no hard-and-fast rules can be relied upon to produce good locations in any set of circumstances. Possibly, the nearest approach to an axiom is that "A good location should fit the country." This does not mean that the road should follow every twist and curve of the landscape or avoid every bump or hill. However, it does mean that within the limits imposed by the geometric standards there should be a conscious effort to go around the largest hills, rather than over them and to avoid obstacles where this can be done without great sacrifice of distance, or directness.

Land ownership exerts a decided influence upon the detailed highway location; often even more than the configuration of the terrain. This is true particularly in the states erected out of the Public Domain, in which lands were divided into sections by the Government before sale to settlers. In these states land use patterns, and especially the net of local roads, have developed around the rectangular grid of section lines. In these states an intelligent rural highway location cannot be made without advance knowledge of land ownership boundaries; otherwise there is grave danger of greatly damaging farms as productive units by carving them up unwisely.

There is a great difference between fitting a heavy-traffic turnpike to the landscape and fitting a low-grade farm-to-market road. This is so because the geometric standards of the high-speed road require curves of longer radius, much easier grades, and longer vertical curves than would be needed for a local land-service road. Obviously a crooked ridge which might accommodate a narrow county road carrying only a few vehicles per day would be completely inadequate for a high-speed interstate highway with an average daily traffic in the thousands.

In searching the ground for a route for his proposed highway the locator is influenced not only by the geometric standards required for the road, but also by his own ideas of what constitutes a good location. The locators of the first motor highways were men who had received their training in railroad location, and they carried a predilection for long tangents over into highway work. The railroads sought long straightaways, because they permitted higher operating speeds with greater safety from possible derailment, than did curved track. Also, due to absence of side pressure on the rails maintenance costs were less on straight tracks.

Copying the railroads, early highway locators also laid out long tangents, but were not nearly as particular in seeking easy grades as the railroad locators. This freedom from grade limitation came about as a result of the hill-climbing ability of the motor vehicle which, from its earliest beginnings, exceeded that of the horse team or the steam locomotive, and enabled the highway locator to ignore many terrain obstacles. Instead of seeking a location closely fitting the landscape he often shortened road distance by going directly across country, producing the familiar "roller coaster" profiles on which, in spite of long tangents, passing opportunities for motorists are few because of inadequate vertical sight distance.

"Long tangent thinking" is strongly entrenched in the highway field, and it usually has as its companion the idea that curvature is intrinsically bad and should be avoided. This leads inevitably to locations composed of the longest possible tangents, joined by the shortest possible curves, often of minimum radius for the design speed. In very flat country the long tangent location may be the most natural and sensible location possible, especially in public land states where long straight lines are the dominant pattern of the landscape. The real danger involved in the long tangent approach to location is that in pursuing straightness as a major objective the locator may force the road through or over obstacles that should better be avoided for construction economy, or other reasons. Another real defect of long tangent locations is monotony, which may cause drivers to fall asleep at the wheel.

While the long tangent philosophy of location may dominate highway location at present, it is not the only school of thought, and may eventually be superseded by newer ideas of curvilinear or semi-curvilinear location. Curvilinear location is essentially a concept borrowed from landscape architecture,

to which long straight lines are unnatural and therefore abhorrent. Without doubt, a curving alignment is more graceful and presents greater opportunity to avoid obstacles, both natural and man-made, than one of long tangents. However, in some earlier examples where this method of design was followed, principally on parkways, there was a tendency to eliminate tangents almost entirely, and even to use curves where the natural conditions would have made tangents preferable. Some of these earlier curvilinear highways were designed for what would be considered low speeds today, and it has been said that their modernization will prove very costly because of their generally crooked alignment.

Perhaps the most promising development in modern highway design is "semi-curvilinear" location, in which long flat curves are combined with tangents of moderate length. This approach to design recognizes that the motorist can negotiate long flat curves at full speed as safely as he can drive on tangents. By relaxing the long tangent requirement, the locator allows himself more freedom of maneuver to avoid natural obstacles, to minimize property damage, or to take advantage of favorable sites for interchanges, railroad crossings or bridges. He is thus able to find a more economical location and at the same time one of greater variety, and therefore less subject to "highway hypnosis."

At this point traffic economists will undoubtedly inquire how much extra distance is introduced into the location by the use of semi-curvilinear location. Such direct comparisons as have been made indicate that the differences are quite small—of the magnitude of 1 to 2 per cent increase in length for the semi-curvilinear location—and that the extra distance is compensated for in part by improvement in grades. In three middlewestern states semi-curvilinear locations were projected on topographic strips made originally for long-tangent locations. The mileages obtained for the semi-curvilinear locations were then compared with those for the long-tangent locations with the results shown in Table 1.

Table 1

Comparison between length of long-tangent locations and semi-curvilinear locations projected through the same route bands.

Termini	Length of long-tangent location (Miles)	Length of semi-curvilinear location (Miles)	Difference (Miles)	Percentage of long-tangent length
Fish Lake-Bryant Lake, Minn. (Por.)	10.019	10.177	0.158	101.6
Barnhart-Bloomsdale, Missouri	27.729	27.978	0.249	100.9
New Underwood-Wicksville, South Dakota	12.454	12.621	0.167	101.3

Immense strides in the improvement of divided highway designs have followed the adoption of semi-curvilinear alignment in combination with independent geometric treatment of the two roadways. It is interesting to trace the evolution of this most modern of highway types from its beginnings in the double-track railroad.

The railroad train is confined to a fixed path by the rails, and where traffic is at all heavy two such paths are provided so that simultaneous train movements are possible in both directions. Overtaking is not possible except at sidings, and here can only be effected because both trains are under outside control and are not free to move as they please. Mobility and comparative absence from exterior control is a fundamental difference which distinguishes motor transportation from rail transportation. All enginemen on railroads are experts and they are not allowed to drive until their expertness is proven. This happy state is far from attainment with motorists: therefore the chance of human error is more continually present. And so, wherever traffic is heavy the highway engineer seeks to divide the traffic stream into two one-way components, producing the divided highway so prevalent today.

In the early days highway engineers thought of the two motor roadways of a divided highway as two tracks on a single roadbed just as a railroad man would visualize his two one-way tracks. As hundreds of miles of such highways were built in the past 20 years, there was a gradual evolution in the thinking of highway engineers about the neutral ground or "median" as they called it, between the roadways. At first, to save right of way and grading cost the median was kept rather narrow—only 4 to 6 feet wide—and it was thought of only as a barrier or fence to keep the two opposing traffic streams apart. Gradually however it was widened to reduce headlight glare and to make a refuge for left-hand turners to await a break in the traffic stream to complete their turns; and to reduce the possibility that a car out of control might ricochet across the barrier into the oncoming traffic from the other direction. Finally, someone realized that there was really no reason for a uniform width of median at all; that the two traffic streams were entirely independent and need not be parallel to each other either in horizontal or vertical position. This revolutionary discovery was made many years ago but was not widely used until just before World War II. It was first applied extensively and consistently by the Bureau of Public Roads on the Washington-Baltimore Parkway; later outstanding examples were the New York Thruway, The Wilbur Cross Parkway in Connecticut and The Garden State Parkway in New Jersey. This principle at one stroke alleviates the problems of headlight glare and traffic noise, largely eliminates danger of head-on collision, provides more interesting and restful driving conditions and enhances the beauty of the highway and its roadsides. Its principal disadvantage (and not a small one either, especially in cities and urban areas) is the greater area required for right of way. Also, it requires more thorough study and greater engineering skill to design and lay out; for plans for this type of design cannot be readily standardized and ground out on an assembly line. These disadvantages, however, are often offset by reduced construction costs, resulting from more careful design.

Independent roadway design is especially effective where the location is with the general trend of the country, as where it is following a valley, a long continuous hillside or ridge. Where topographic conditions are favorable, impressive construction savings are possible. In one such example reported by Mr. Joseph Barnett, M. ASCE, the grading requirement was reduced from 280,000 cubic yards per mile for conventional 4-lane design to 60,000 cubic yards per mile for independent roadway design.[2]

On the other hand, where the location is "bucking the country" at right angles to the general trend of the ridges and valleys independent roadway

2. Civil Engineering, Vol. 25, August 1955, p. 497.

design produces very small dollar savings, or none at all. However, even where no cost advantage in construction accrues, variable median design may still be worthwhile because of improvement in appearance and increased safety resulting from relief of monotony and elimination of "road hypnosis," and from reduction of headlight glare.

As was mentioned earlier excessive haste and pressure militate against good highway location and design. To understand why this is so one needs to know something of the location process itself, and this knowledge can best be imparted by harking back again to the early railroad location engineers.

The earliest railroad engineers—men like the explorer Colonel Stephen H. Long, who was chief engineer of the Baltimore and Ohio Railroad in the 1830's—picked their locations by the "direct method," that is by walking through the country with a surveying party, laying the centerline as they went. Later, in the 'Nineties, competition between railroads forced them to find locations with flatter grades that could be operated with greater loads and lower consumption of fuel; and here, the "direct method" broke down because the locator could see only what was within the immediate range of his vision. A better location might lie over the next hill but he could not see it. Gradually, however, under the leadership of such engineers as A. M. Wellington, M. ASCE, and Fred Lavis, M. ASCE, another method developed, which for lack of a better name we might call the "topographic method." Instead of staking the centerline directly on the ground, the locator ran a random line, or where there were a number of possible locations, several random lines, and used these as "base lines" or backbones upon which to construct a topographic strip map of the country through which he was passing. When he had several miles of such topography, he would spread the map out on a long table, and he could then look down upon it as an observer would from a balloon. Instead of seeing only the hill in front of him, he could "see" the country in miniature for miles ahead. He could thus pick out the vital spots or "controls" which determine the best location, and thread his location through them with a pencil line on the map, at the same time observing that his curves were no sharper than the rules of the railroad allowed.

This method gave the locator of the early 1900's a tremendous advantage over his grandfather of the 1830's in establishing his first trial line. But thereafter his advantage was even greater. If Colonel Long was dissatisfied with his first trial location he had no other recourse than to take to the field on foot and run another line or revise the first. And seldom did it occur that the final location was achieved without two or more field revisions. Mr. Lavis, however, could make as many revisions as he pleased in the cosy comfort of his tent without going out into the field at all, merely by sketching another line on his topographic map. When he was satisfied with his "paper projection," only then did he go out to the field and set stakes for the final location.

The topographic method, as developed by railroad engineers divided location into five stages or steps. The first of these was the reconnaissance, which was not a survey in the ordinary sense, but rather a rapid and critical general examination of a wide belt of country between assigned termini to determine its principal topographic features, and its potential traffic or revenue producing possibilities. Quite often the need to pick up traffic for the railroad drew the location away from the most direct route or the cheapest to construct. During the reconnaissance the locator selected intermediate points or controls on the route. Railroad locators attached the utmost importance to

good reconnaissance, and in their writing the perils of hasty and superficial work in this stage are stressed again and again.

In the second stage of location obviously unsuitable routes were eliminated and the choice narrowed to one or at most two possibilities for investigation by ground surveys. The topographic strip map mentioned previously was produced during the third stage, and the paper projection on the strip map during the fourth stage, while the final operation was the staking of the paper projection on the ground as the final location.

The topographic method is still the best for locating not only railroads, but highways as well. Furthermore, its application has been tremendously improved and made much easier by the developments of modern technology. Aerial photography and the preparation of maps from aerial photographs, called "photogrammetry," have made such enormous strides during the past 10 years that it is now possible to make a complete highway location down to the preparation of final plans without driving a single stake in the ground or alarming a single property owner.

Airplanes have simplified reconnaissance and made it much more reliable. Now in an hour or two of observation from the air the locator can cover more terrain than would be possible in days or weeks of exploration on foot or horseback, and do it better. Furthermore, the extension of reliable topographic mapping over entire states and regions has made it possible in many areas to perform most of the reconnaissance by map study alone.

By intensive stereoscopic examination of vertical aerial photographs, route selection can be completed in a fraction of the time formerly required. When he looks at overlapping pairs of photographs through the stereoscope the observer sees the relief "stand up" and can instantly perceive the most promising available highway locations, as well as the impossible ones. By stereoscopic study combined with measurements scaled from the photographs he can actually trace a grade line on the photographs and thus ascertain whether a route is attainable within grade limitations. Obviously such office studies of aerial photographs save the locator an immense amount of time and energy which otherwise would be required for field exploration and study. Furthermore, good photo-interpretation will disclose areas of good and bad soil, which may have a bearing on the location.

A third application of the new techniques is in the preparation of the topographic strip maps so essential to the success of the topographic method. Modern surveying instruments, using the principles of radar enable mappers to perform the control surveys for the strip map in a fraction of the time formerly required, and with greater accuracy. By means of complex stereoscopic plotting instruments of unbelievable accuracy photogrammetric engineers can now produce contour maps from aerial photographs of greater accuracy than is possible by ground survey methods, and in less time. Furthermore, as compared to ground methods, photogrammetry can provide two to three times the width of topographic coverage for the same money. This greater width of coverage greatly strengthens the topographic method of location by providing a wider field for detailed map study in the projection stage. One can imagine how great locators of the past, such as Long, Lavis or Stevens, would have welcomed such a wondrous tool and rushed out to apply it to their railroad locations!

Where photogrammetry is properly used in location and design (and such use is happily becoming more and more prevalent) good or at least passable locations are much more probable than with the old direct method. Yet in

spite of the proved superiority of the topographic method "direct" location is still used for hundreds of miles of important highways every year. Why is this?

Supposed savings in engineering effort and a desire to rush the location through without waiting for the production of topographic strip maps are probably the principal reasons for the persistence of obsolete direct location methods. The writer has heard the statement many times that a complete direct location can often be produced in the same time and at the same cost as would be required to obtain the topographic strip alone where the topographic method is used. Such statements while literally true, overlook the fact that the more careful study required to project an acceptable location on the strip map may save much more in construction cost than the direct location saved in engineering expense.

Direct locations can usually be justified for low-grade local roads, and for higher-type roads where the proposed improvement is closely confined to an existing road or right of way. But for new locations of important highways the topographic method will almost invariably produce better locations at lower overall cost than direct location. Furthermore, these better locations may be produced with less expenditure of the highly skilled and experienced engineering effort needed for good locations.

Suppose for example that the main controls for a road have been selected by an experienced locator and the route has been thus narrowed down to a band about 1/2-mile wide which will contain the desired location. The state or other road-building authority can then contract with a firm of photogrammetric engineers for the necessary topographic map coverage, freeing the locator, who may be a man of many years experience, for other locations. Later, when the topography is received from the photogrammetrist a skilled and experienced projector can analyze it in detail in the office, running several trial pencil lines if necessary. In country of average surveying difficulty such projection can be done by an engineer of reasonable skill at speeds of 4 to 6 times the speed of direct ground location by an experienced locator. And while the projection process is under way there is no field party sitting around waiting for directions!

After the paper projection is completed it can be transferred to the ground by any capable survey party without the need for an experienced locating engineer's presence, except for final review.

The selection of the route band is of course the most critical and important of all operations of highway location, and it demands talents of the highest order. Only slightly less important is the role of the projector who places the paper projection upon the topographic strip map. He must be able to visualize the location in three dimensions, and to compare and analyze an immense number of facts which may influence the detailed location.

Modern techniques, as we have seen, have greatly improved and speeded up reconnaissance, route selection and the preparation of the topographic strip map. The fourth step of the topographic method, however, has remained substantially unchanged for 70 years. Electronic scanning machines may eventually be developed to assist the projector, but at present the projection of the location on the strip map is still a "cut and try" process requiring skill, patience and thoroughness for success. The best projectors seldom find the best location on their first trial, and do not hesitate to make other projections if there is the slightest possibility of improving the projection thereby. Indeed, overlooking good locations through haste, lack of imagination or lack of

resourcefulness is a danger to be guarded against during the projection stage.

The actual projection is done with a "spline," an instrument borrowed from naval architecture by the highway engineer. This is a long flexible ruler which is positioned on the map so that it passes through or near the principal controls, and is held in place over these points by weights of peculiar shape. The elastic spline springs naturally into smooth curves between the points where it is restrained by the weights. By moving the weights slightly the designer positions the spline to more closely fit the topography, improve bridge approaches, reduce skews for railroad crossings or otherwise improve the location.

He then draws a pencil line along the spline, producing a smooth curving line on the map. This line is stationed with dividers after which the designer prepares a profile by plotting the station and elevation where the spline line crosses each contour of the map. He then lays a grade line on the profile, and checks it for sight distance, approximate earthwork balance, and geometric appearance.

This analysis of the projection profile is always done in conjunction with the spline line, because the two are in fact inseparable. Quite often a bad profile can be corrected only by selecting a different spline line location on the map. Furthermore, changes in either horizontal or vertical position often affect each other in a "chain reaction," so that a change in one place may affect the location for a mile in either direction. This is especially true where a high-standard location is projected through moderately rough country.

At this stage of location exact balance of earthwork quantities is not especially important, and should not be attempted; otherwise the projector will bog down in a mass of detail from which he will never extricate himself. (The writer has long questioned whether exact balance is necessary or desirable in any event, as he has seen too many locations botched with minor humps and ripples in the grade to achieve it. It is much better to strive for a good grade line with an excess of fill and make up the excavation deficiency from borrow.)

The projector should however pay a great deal of attention to the geometric inter-relationship of grade and alignment, avoiding the geometric absurdities which curse some of our older roads. Among these are the "broken-back curve," or two curves in the same direction joined by a short tangent; the "swag," which is a short dip in a long grade tangent; and the sharp reverse. An alignment of alternating right-hand and left-hand curves is the most pleasing to the eye and the most natural to drive. It is always good to preserve a reasonable length of tangent between curves to give the driver an opportunity to get "straightened out" psychologically. The longer and flatter the curves, the longer the tangent between them should be. For example, in an alignment of long 15-minute, 30-minute and one degree curves, such as might be adopted in very flat country, tangent distances of 1/2-mile or even 1 mile should be preserved between curves in opposite directions, if possible.

Often considerations of appearance may require a better geometric design than would be required to accommodate traffic. An example of this is the sag-vertical curve, where greater length is required for appearance than is needed for satisfactory sight distance. In ordinary country the writer recommends minimum sag-verticals of 1,000 feet to avoid the appearance of a kink in the grade line. Similarly, a small horizontal angle should be turned by a horizontal curve at least 1,000 feet long to avoid the appearance of a kink.

Such minor angles are often found in section line locations, as are "jogs" where the road centerline is offset parallel to itself. Jogs should be negotiated by using very long and flat reversed curves, and for satisfactory appearance the writer recommends using curves no sharper than 15 minutes for this purpose. Another excellent way to take care of jogs on a divided highway is to line up one roadway with each leg of the jog and take out the offset in the median.

Where the route is confined by right-of-way considerations pretty closely to section lines, or quarter section lines, it is often difficult to achieve even a small degree of curvilinearity in the location. However, even here advantage can be taken of minor features such as section-line jogs, mentioned above, or the right of way may be acquired entirely on one side or the other of the section line rather than straddle of it, and the location shifted from one side to the other by means of very flat reversed curves. This latter approach may also enable the designer to minimize property damage by shifting away from major groups of farm buildings, or from costly improvements such as large stock ponds, orchards or wind breaks. Another possibility is to widen the median at intervals where changes of direction occur to 100 feet or even 200 feet by using a flatter curve for the inside roadway than for the outside roadway.

The superiority of the topographic method over direct location is most readily apparent in grade-controlled locations such as the long continuous ascents required to pass over mountains. The projection of such locations is difficult on a good topographic map, but becomes unbelievably complex when direct location is attempted. For divided highways on grade-controlled locations it is almost invariably cheaper and better to use split level or independent roadway design than to place both roadways on the same grade and parallel to each other. Usually a steeper grade will be permissible on the down-grade roadway. In such situations, the up-grade roadway is projected first as a grade-controlled location; the down-grade roadway is then projected as close to the up-grade roadway as the terrain and the design standards will permit. Possibly the most spectacular example of a divided highway with independent roadways is the Via Anchieta, from Sao Paulo to Santos, Brazil, illustrated in the magazine LIFE for October 21, 1957. The boldness of this location staggers the imagination.

After the projection of alignment and grade is completed all of the important engineering decisions have been made, and the preparation of detailed plans and staking out of the centerline on the ground are routine operations that can be performed in the usual manner, however, since spline lines have no regular geometric properties it is necessary first to resolve them into circular elements before they are shown on the plans or staked. This can be done either with templates, or by calculation, without great difficulty. Also, spiral transitions can be added where required.

Painstaking location and careful design require considerable engineering effort. Highway design is still to a great extent a process of successive approximations, with each trial giving a more refined and economical plan, so that within limits the more time and effort spent in design, the better the final result. The expression "within limits" is used advisedly since there always comes a time when the law of diminishing returns asserts itself, and extreme fussiness and refinement in engineering do not produce commensurate results in lower construction cost or better facilities.

A very promising recent development in location analysis is the Digital Terrain Model System by means of which the relative merits of a number of locations through a given strip of topography can be rapidly compared using an electronic computer. Further refinements in this system may eventually relieve the designer of most of the drudgery of projections, freeing his energies for the more important engineering decisions.

The modern highway engineer has at his fingertips the finest tools a locator ever had to work with, plus the benefit of 40 years of evolution in motor highway design. The proper application of these advanced techniques to the art of location now makes it possible to produce the beautiful, restful and efficient highways that we need for the future.

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Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

GLOSSARY OF ELECTRONIC COMPUTER TERMINOLOGY

Progress Report of the Committee on Increasing Highway Engineering Productivity of the Highway Division

Glossary of Electronic Computer Terminology compiled by the Committee on Increasing Highway Engineering Productivity of the Highway Division. This glossary which covers approximately 350 commonly used terms, provides a working knowledge of computer terminology both for the engineer directly concerned with computer program development and for those whose work requires a more general understanding of the terms peculiar to this rapidly developing field.

FOREWORD

Nearly all of the major highway engineering organizations in the United States are now using electronic computers for engineering computations. The range of applications has increased steadily and a further continuing growth seems certain. To the highway engineers in these organizations, an understanding of electronic computer terminology is becoming increasingly important. The purpose of this glossary is to provide such an understanding.

Terms printed in capital letters are those of particular interest to the highway engineer who is not closely associated with computer operations but who must communicate with those who are. Other terms, of primary interest to highway engineers and others concerned with computer program development or computer operation, are also included but are printed in small letters. It is hoped that this device will facilitate the use of the glossary.

ACCESS, RANDOM

access to storage under conditions in which the next position from which information is to be obtained is in no way dependent on the previous one.

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ACCESS TIME

the time interval between the instant at which information is: (a) called for from storage and the instant at which delivery is completed, i.e., the read time; or (b) ready for storage and the instant at which storage is completed, i.e., the write time.

ACCUMULATOR

the register (and associated equipment) in the arithmetic unit in which are formed sums and other arithmetical and logical results; a unit in a digital computer where numbers are totaled, i.e., accumulated. Often the accumulator stores one quantity and upon receipt of any second quantity, it forms and stores the sum of the first and second quantities.

ACCURACY

freedom from error. Accuracy contrasts with precision; e.g., a four-place table, correctly computed, is accurate; a six-place table containing an error is more precise, but not accurate.

Adder

a device capable of forming the sum of two quantities.

ADDRESS

a label such as an integer or other set of characters which identifies a cell, register, location or device in which information is stored.

Address, absolute

the label (s) assigned by the machine designer to a particular storage location; specific address.

Address, relative

a label used to identify a word in a routine or sub-routine with respect to its position within that routine or subroutine. Relative addresses are translated into absolute addresses by the addition of some specific "reference" address, usually that at which the first word of the routine is stored, e.g., if a relative address instruction specifies an address n and the address of the first word of the routine is k, then the absolute address is n + k.

Address, symbolic

a label chosen to identify a particular word, function or other information in a routine, independent of the location of the information within the routine.

ALLOCATE

to assign storage locations to the main routines and subroutines, thereby fixing the absolute values of any symbolic addresses.

Alphameric or alphanumeric

alphabetic and numeric.

ANALOG or ANALOGUE

the representation of numerical quantities by means of physical variables, e.g., translation, rotation, voltage, resistance; contrasted with "digital". (Also see COMPUTER, ANALOG)

And-operator

a logical operator which has the property such that if P and Q are two statements, then the statement "P and Q" is true or false precisely according to the following table of possible combinations:

P	Q	P and Q
false	false	false
false	true	false
true	false	false
true	true	true

The and-operator is often represented by a centered dot (·), or by no sign, as in P · Q or PQ.

ARITHMETIC UNIT

that portion of the hardware of an automatic computer in which arithmetical and logical operations are performed.

Assemble

to integrate subroutines (supplied, selected or generated) into the main routine by adapting or specializing to the task at hand by means of preset parameters, by adapting or changing relative and symbolic addresses to absolute form, or incorporating, or placing in storage.

Automation

the entire field of investigation, design, development, application and methods of rendering or making processes or machines self-acting or self-moving; rendering automatic; theory, art or technique of making a device, machine, process or procedure fully automatic.

Band

a group of recording tracks on a magnetic drum.

BASE

a number base, a quantity used implicitly to define some system of representing numbers by positional notation; radix.

BINARY

a characteristic or property involving a selection, choice or condition in which there are but two possible alternatives.

BINARY CODED DECIMAL NOTATION

a system of number representation in which each decimal digit of the number is represented by a group of binary digits (see CODED DECIMAL NOTATION).

BINARY DIGIT

a digit in the binary scale of notation. It may be either 0 (zero) or 1 (one). It is equivalent to an "on" condition or an "off" condition, a "yes" or a "no", etc.

BINARY NOTATION

a method of representing numbers based on a radix of two. The decimal number 13.25 is expressed in binary notation as 1101.01 in which the digits are coefficients of successive powers of 2. Thus 1101.01 means 1 times 2 cubed plus 1 times 2 squared plus 0 times 2 to the first power plus 1 times 2 to the zero power plus 0 times 2 to the minus one power plus 1 times 2 to the minus two power or $8 + 4 + 0 + 1 + 0 + .25 = 13.25$.

BINARY NUMBER

a number written in binary notation.

Binary point

in a binary number the point which separates the integral and fractional parts of the number, analogous to the decimal point in a decimal number.

BINARY TO DECIMAL CONVERSION

the mathematical process of converting a number written in binary notation to the equivalent number expressed in decimal notation.

BIQUINARY NOTATION

a method of representing numbers in which the base is alternately 2 and 5, e.g., the number 3671 in decimal notation is 03 11 12 01 in biquinary notation; the first digit of each of these pairs of digits counts 0 or 1 units of five, and the second counts 0, 1, 2, 3 or 4 units, e.g., 12 in biquinary notation is $5 + 2 = 7$ in decimal notation. Biquinary notation is used in the abacus as well as in some computers.

BIT

a binary digit; a contraction of two words "binary" and "digit"; a single pulse in a group of pulses.

BLOCK

a group of words considered or transported as a unit; an item; a record; in flow charts, an assembly of boxes, each box representing a logical unit of programming.

BLOCK DIAGRAM

a schematic representation of the sequence of subroutines involved in the solution of a particular type of problem; a more general and less detailed representation than a flow chart.

Block, input

a section of internal storage of a computer reserved for the receiving and processing of input information.

Block sort

a sort on one or more significant factors as a means of systematically subdividing large volumes of records.

Block transfer

the movement of a group of words from one section of internal storage to another or from external storage to internal storage.

Bootstrap

the coded instructions at the beginning of an input tape, together with one or two instructions inserted into the computer by switches or buttons, used to place a routine in storage.

BRANCH

a conditional jump. (Also see JUMP)

Breakpoint

a point in a routine at which the computer may, under the control of a manually-set switch, be stopped for a visual check of progress; in flow charting, a term indicating an interruption in the continuity of the chart.

Buffer

an isolating circuit used to avoid any reaction of a driven circuit upon the corresponding driving circuit, e.g., a circuit having an output and a multiplicity of inputs so designed that the output is energized whenever one or more inputs are energized. Thus, a buffer performs the circuit function which is equivalent to the logical "OR" operation. (Also see STORAGE, BUFFER)

Call-number

a set of characters identifying a subroutine and containing information concerning parameters to be inserted in the subroutine, information to be used in generating the subroutine, or information related to the operands.

Call-word

a call-number which fills exactly one word.

CAPACITY

the measurement of the maximum amount of material which can be stored. The capacity of a computer may be limited to ten decimal digits or between the upper and lower limits of the numbers which may be processed in a computer register, e.g., the accumulator such as from + .00000 00001 to + .99999 99999. Quantities which exceed the capacity of the computer cause an overflow condition which usually interrupts its operation in some way; the quantity of information which may be stored in a storage unit.

Card or punch card

stiff paper stock of a prescribed size and shape on which data may be recorded by punched holes.

Card column

one of a number of columns (45, 80 or 90) contained on a punch card.

Card feed

a mechanism which moves cards one-by-one into a machine.

Card punch

a mechanism which punches cards automatically or a machine in which cards are punched by manual operation.

Card reader

a mechanism by means of which the information recorded on punched car[ds] is read mechanically by metal fingers, electrically by wire brushes or electronically.

Cathode ray tube

a large electronic tube containing a screen on which information is store[d] by means of a multigrid modulated beam of electrons from a thermionic emitter, the storage being effected by means of the presence or absence [of] spots bearing electrostatic charges; a similar tube with screen for visual display of output in graphic form.

Cell

storage for one unit of information, usually one character or one word; usually a storage location identified by all or part of an address.

Channel

a path along which information, particularly a series of digits or characters, may flow. In storage which is serial by character and parallel by bit (e.g., a magnetic tape or drum in some coded decimal computers), a channel comprises several parallel tracks. In a circulating storage, a channel is one recirculating path containing a fixed number of words stor[ed] serially by word.

CHARACTER

one of a set of elementary symbols such as those which appear on the keys of a typewriter. The symbols may include the decimal digits 0 through 9, the letters A through Z, punctuation marks, operation symbols, and any other single symbol which a computer may read, store or write; a representation of such a symbol in a pattern of ones and zeros or a pattern of pulses or states.

Check

a means of verification of information during or after an operation.

Check, built-in or automatic

any provision constructed in hardware for verifying the accuracy of information transmitted, manipulated, or stored by any unit or device in a computer.

Check, duplication

a check which requires that the results of two independent performances either concurrently on duplicate equipment or at a later time on the same equipment) of the same operation be identical.

Check, forbidden combination

a check (usually automatic) which tests for the occurrence of a nonpermissible code expression. A self-checking code (or error-detecting code) uses code expressions such that one or more errors in a code expression produces a forbidden combination. A parity check makes use of a self-checking code employing binary digits in which the total number of ones (or zeros) in each permissible code expression is always even or always odd. The check may be arranged for either even parity or odd parity. A redundancy check employs a self-checking code which makes use of redundant digits called check digits.

Check, mathematical or arithmetic

a check which makes use of mathematical identities or other properties, frequently with some degree of discrepancy being acceptable, e.g., checking multiplication by verifying that A x B = B x A; checking a tabulated function by differencing; etc.

Check, modulo N

a form of check digits, such that the number of ones in each number A operated upon is compared with a check number B, carried along with A and equal to the remainder of A when divided by N, e.g., in a "modulo 4 check", the check number will be 0, 1, 2 or 3 and the remainder of A when divided by 4 must equal the check number B—if not, an error or malfunction has occurred; a method of verification by congruences, e.g., casting out nines.

Check, odd-even

a check system in which a one or zero is carried along in a word depending upon whether the total number of ones (or zeros) in a word is odd or even.

Check, parity

a summation check in which the binary digits in a character or word are added and the sum checked against a single previously computed parity digit, i.e., a check which tests whether the number of ones is odd or even.

Check, programmed

a system of checking in which the correctness of a program and the functioning of the computer is determined either by running a sample problem with similar programming and known answer, including mathematical checks such as comparing A x B with B x A and usually where reliance is placed on a high probability of correctness rather than on built-in error-detection circuits, or by constructing a checking system in the program being used to provide for checking during the actual running of the problem.

Check, redundant

a check which uses extra digits, short of complete duplication to help detect malfunctions and mistakes.

Check, summation

a redundant check in which groups of digits are summed, usually without regard for overflow, and the sum checked against a previously computed sum to verify accuracy.

Check, transfer

verification of transmitted information by temporary storing, retransmitting and comparing.

Check, twin

a continuous duplication check achieved by duplication of hardware and automatic comparison.

Checking, marginal

a system or method of determining computer circuit weaknesses and incipient malfunctions by varying the power applied to various circuits.

CLEAR

to replace all information in a storage device by zeros as expressed in the number system employed.

Clock frequency

the master frequency of periodic pulses which schedules the operation of the computer.

CODE

a system of symbols for representing information in a computer and the rules for associating them; to express information, particularly problem data, in language acceptable to a specific computer.

CODE, COMPUTER

the code representing the operations built into the hardware of the computer.

Code, excess three

a coded decimal notation which represents each decimal digit as the corresponding binary number plus three, e.g., the decimal digits 0, 1, 7 and 9 are represented as 0011, 0100, 1010 and 1100 respectively. In this notation, the numbers from five to nine are complements of the numbers from four to zero.

CODE, INSTRUCTION

an artificial language for expressing the instructions to be carried out by the computer. In automatically sequenced computers, the instruction code is used when describing or expressing sequences of instructions. Each instruction usually contains a part specifying the operation to be performed and one or more addresses which identify particular locations in storage. Sometimes the address part of the instruction is not intended to specify a location in storage but is used for some other purpose. If more than one address is included in an instruction, the code is called a multiple-address code.

CODE, MULTIPLE-ADDRESS

an instruction code in which more than one address or storage location is included in an instruction. In a typical instruction using a four-address code, the addresses specify the locations of two operands, the destination of the result and the location of the next instruction in the sequence. In a typical three-address instruction, the fourth address specifying the location of the next instruction is dispensed with, the instructions being taken from storage in a preassigned order. In a two-address instruction, the addresses may specify the locations of the two operands, or of one operand and the destination of the result or of one operand and the location of the next instruction.

Code, operational

that part of an instruction which designates the operation to be performed.

Coded decimal notation

a form of notation in which each decimal digit is represented by a pattern of binary ones and zeros, e.g., in the 8 - 4 - 2 - 1 coded decimal notation, the number 12 is represented as 0001 0010 (for the decimal digits 1 and 2) whereas in pure binary notation, twelve is represented as 1100. Other coded decimal notations are known as "5 - 4 - 2 - 1", "excess-three", "2 - 4 - 2 - 1", etc.

CODING

the process of expressing computer instructions in code. The code used may be the computer code or some other code which can be machine converted to computer code.

Coding, absolute, relative or symbolic

coding in which one uses absolute, relative or symbolic addresses, respectively.

Coding, alphabetic

a system of abbreviations used in preparing information for input into a computer such that information is reported in the form of letters, e.g., New York as NY, carriage return as CN, etc.

CODING, AUTOMATIC

any technique in which a computer is used to help bridge the gap between some "easiest" form, intellectually and manually, of describing the steps to be followed in solving a given problem and some "most efficient" final coding of the problem for a specific computer. Two basic forms are termed compiling routine and interpretive routine.

Coding, numeric

a system of representation used in the preparation of information for machine acceptance by reducing all information to numerical terms; in contrast to alphabetic coding.

Collate

to combine two or more similarly ordered sets of items to produce another ordered set composed of information from the original sets. Both the number of items and the size of individual items in the resulting set may differ from those of either of the original sets, e.g., sequence 23, 24, 48 may be collated into 12, 23, 24, 29, 42, 48.

Collator

a machine which has two card feeds, four card pockets and three stations at which a card may be compared or sequenced with regard to other cards so as to select a pocket in which it is to be placed, e.g., the machine is suitable for matching detail cards with master cards, merging cards in proper sequence, etc.

COLUMN

one of the character or digit positions in a positional notation representation of a unit of information. Columns are usually numbered from right to left, zero being the rightmost column if there is no decimal (or binary, or other) point, or the column immediately to the left of the point if there is one. Also a position or place in a number in which the position designates the power of the base and the digit is the coefficient, e.g., in 3876, the 8 is the coefficient of 10^2, the position of the 8 designating the 2.

Command

a pulse, signal or set of signals initiating one step in the performance of a computer operation (see INSTRUCTION).

Comparator

a device for comparing two different transcriptions of the same information to verify the accuracy of transcription, storage, arithmetic operation or other process, in which a signal is given dependent upon the relative state of two items, i.e., larger, smaller, equal, etc.

COMPARE

to examine the representation of a quantity for the purpose of determining its relationship to zero, or of two quantities for the purpose of determining identity or relative magnitude.

Comparison

determining the identity, relative magnitude and relative sign of two quantities and thereby initiating an action.

COMPARISON, LOGICAL

the operation concerned with the determination of similarity or dissimilarity of two items, e.g., if A and B are alike, the result shall be "1" or yes, if A and B are not alike, the result shall be "0" or no.

COMPILER or COMPILING ROUTINE

a program-making routine which before the desired computation is started, translates a program expressed in pseudo-code into computer code (or into another pseudo-code for further translation by an "interpreter").

Complement

a quantity which is derived from a given quantity, expressed to the base n, by one of the following rules and which is frequently used to represent the negative of the given quantity: (a) complement on n—subtract each digit of the given quantity from n - 1, add unity to the least significant digit, and perform all resultant carrys, e.g., the twos complement of binary 11010 is 00110, the tens complement of decimal 456 is 544; (b) complement on n - 1 —subtract each digit of the given quantity from n - 1, e.g., the ones complement of binary 11010 is 00101, the nines complement of decimal 456 is 543.

COMPUTER

any device capable of accepting information, applying prescribed processes to the information, and supplying the results of these processes; sometimes, more specifically, a device for performing sequences of arithmetic and logical operations; sometimes, still more specifically, a stored-program digital computer capable of executing sequences of internally-stored instructions, as opposed to calculators on which the sequence is impressed manually (desk calculator) or from tape or cards (card programmed calculator).

COMPUTER, ANALOG

a calculating device which uses physical analogs of the quantities involved; a calculating machine which solves problems by translating physical conditions like flow, temperature or pressure into electrical quantities and using electrical equivalent circuits for the physical phenomenon.

Computer, asynchronous

a calculating device in which the performance of any operation starts as a result of a signal that the previous operation has been completed; contrasted with synchronous computer.

Computer, automatic

a calculating device which handles long sequences of operations without human intervention.

COMPUTER, DIGITAL

a calculating device utilizing numbers to express all the variables and quantities of a problem. The numbers may be expressed in coded form as patterns of punched holes, magnetized spots, electrical pulses, etc.

Computer, synchronous

a calculating device in which the performance of all operations is controlled with equally spaced signals from a master clock.

Conditional

subject to the result of a comparison made during computation; subject to human intervention.

Contents

the information stored in any storage medium. Frequently, the symbol ( ) is used to indicate "the contents of", e.g., (m) indicates the contents of the storage location whose address is m, (A) indicates the contents of register A; (T_2) may indicate the contents of the tape on input-output unit 2, etc.

CONTROL

the parts of a digital computer which effect the carrying out of instructions in proper sequence, the interpretation of each instruction, and the application of the proper signals to the arithmetic unit and other parts of the computer in accordance with this interpretation; one or more components in any mechanism responsible for interpreting and carrying out manually initiated directions.

CONTROL SEQUENCE

the normal order of selection of instructions for execution. In some computers, one of the addresses in each instruction specifies the control sequence. In other computers, the sequence is consecutive except where a jump occurs.

CONTROL, SEQUENTIAL

a manner of computer operation such that instructions are fed in a given order to the computer during the solution of a problem.

CONTROL UNIT

that portion of the hardware of an automatic digital computer which directs the sequence of operations, interprets the coded instructions, and initiates the proper commands to the computer circuits to execute the instructions.

CONVERT

to change numerical information from one number base to another (e.g., decimal to binary) or from some form of fixed point to some form of floating point representation or vice versa.

Converter

a unit which changes the language of information from one form to another so as to make it available or acceptable to another machine, e.g., a unit which takes information punched on cards and produces the same information recorded on magnetic tape, possibly including editing in the process.

Copy

to reproduce information in a new location replacing whatever was previously stored there and leaving the source of the information unchanged.

Core, magnetic

a piece of magnetic material capable of assuming and remaining at one of two or more conditions of magnetization, thus capable of providing storage, gating or switching functions, usually of toroidal shape and pulsed or polarized by electric currents carried on wire passing through or wound around the material.

Counter

a device, register or storage location for storing integers, permitting these integers to be increased or decreased by unity or by an arbitrary constant, and capable of being reset to zero or to an arbitrary integer.

Counter, control

a device which records the storage location of the instruction word which is to be operated upon following the instruction word in current use. The control counter may select storage locations in sequence, thus obtaining the next instruction word from the following storage location, unless a transfer or special instruction is encountered.

Cybernetics

the comparative study of the control and intra-communication of information handling machines and nervous systems of animals and man in order to understand and improve communication.

Cycle

a set of operations repeated as a unit; a non-arithmetic shift in which the digits dropped off at one end of a word are returned at the other end in circular fashion. To repeat a set of operations a prescribed number of times including, when required, supplying necessary address changes by arithmetic processes or by means of a hardware device such as a cycle counter.

Cycle count

to increase or decrease the cycle index by unity or by an arbitrary integer.

Cycle criterion

the total number of times a cycle is to be repeated; the register which stores that number.

Cycle index

the number of times a cycle has been executed or the difference, or the negative of the difference, between that number and the number of repititions desired.

Cycle, major

the maximum access time of a recirculating serial storage element; the time for one rotation, e.g., of a magnetic drum or of pulses in an acoustic delay line; a whole number of minor cycles.

Cycle, minor

the word time of a serial computer, including the spacing between words.

Cycle, reset

to return a cycle index to its initial value.

DATA REDUCTION

the art or process of transforming masses of raw test or experimentally obtained data, usually gathered by instrumentation, into useful, ordered or simplified intelligence.

DEBUG

to isolate and remove all malfunctions from a computer or all mistakes from a computer program.

Decimal digit

a digit in the decimal scale of notation, e.g., 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9.

Decimal notation

a method of representing numbers based on a radix of ten.

Decimal point

in a decimal number, the point which separates the integral and fractional parts of the number.

DECIMAL TO BINARY CONVERSION

the mathematical process of converting a number written in decimal notation to the equivalent number expressed in binary notation.

Decode

to ascertain the intended meaning of the individual characters or groups of characters in a coded program.

Delay-line

a device which stores information in a train of pulses or waves, and as a pattern of the presence or absence of such pulses, e.g., electrical delay-lines, magnetic delay-lines, and sonic or acoustic delay-lines.

Density packing

the number of units of useful information contained within a given linear dimension, usually expressed in units per inch, e.g., the number of binary digit magnetized spots stored on tape or drum per linear inch on a single track by a single head.

DIFFERENTIAL ANALYSER

a computer designed specifically for solving many types of differential equations.

Digit

one of the $\underline{n}$ symbols of integral value ranging from 0 to n - 1 inclusive in a scale of numbering of base n, e.g., one of the ten decimal digits, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9.

DIGITAL

the quality of utilizing numbers expressed in digits in a given scale of notation to represent all the quantities that occur in a problem or a calculation.

DIGITIZE

to transform an analog measurement of a physical variable into a numerical value expressed in digital form.

Digits, check

one or more redundant digits in a character or word which depend upon the remaining digits in such a fashion that if a digit changes, the malfunction can be detected, e.g., a given digit may be zero if the sum of other digits in the word is odd, and this (check) digit may be one if the sum of other digits in the word is even.

Digits, equivalent binary

the number of binary digits required to express a number in another base with the same precision, e.g., approximately 3 1/3 times the number of decimal digits is required to express a decimal number in binary form. In coded decimal notation, the number of binary digits required is four times the number of decimal digits.

DOWN TIME

time during which a computer is malfunctioning or not operating correctly due to machine failures; contrasted with available time, idle time or standby time.

DRUM, MAGNETIC

a rotating cylinder on whose magnetic-material coating information is stored in the form of magnetized dipoles, the orientation or polarity of which is used to store information in binary form.

Dummy

an artificial address, instruction, or other unit of information inserted solely to fulfill prescribed conditions (such as word-length or block-length) without affecting operations.

Dump

the removal of all power accidentally or intentionally; the transferral of all or part of the contents of one section of computer memory into another section.

Echo checking

a system of assuring accuracy by reflecting the transmitted information back to the transmitter and comparing the reflected information with that which was transmitted.

EDIT

to rearrange information. Editing may involve the deletion of unwanted data, the selection of pertinent data, the insertion of invariant symbols such as page numbers and typewritten characters, and the application of standard processes such as zero-suppression.

Electronic

pertaining to the application of that branch of science which deals with the motion, emission and behavior of currents of free electrons, especially in vacuum, gas or phototubes and special conductors or semi-conductors. Contrasted with "electric" which pertains to the flow of currents in wires only.

Electronic calculating punch

a punch card machine which in each fraction of a second reads a punch card passing through the machine, performs a number of sequential

Electronic calculating punch (continued)

arithmetic and logical operations electronically and punches a result on the same punch card.

ERASE

to replace all the binary digits in a storage device by binary zeros. In a binary computer, erasing is equivalent to clearing, while in a coded decimal computer where the pulse code for decimal zero may contain binary ones, clearing leaves decimal zeros while erasing leaves all-zero pulse codes.

ERROR

the amount of loss of precision in a quantity; the difference between an accurate quantity and its calculated approximation. Errors occur in numerical methods; mistakes occur in programming, coding, data transcription and machine operation; malfunctions occur in computers and are due to physical limitations of materials and mechanisms.

Error, inherited

the error in the initial values, especially the error inherited from the previous steps in a step-by-step integration.

ERROR, ROUNDING

the error resulting from deleting the less significant digits of a quantity and applying some rule of correction to the part retained. A common round-off rule is to take the quantity to the nearest digit, e.g., pi, 3.14159265...., rounded to four decimals is 3.1416.

ERROR, TRUNCATION

the error resulting from the use of only a finite number of terms of an infinite series, or from the approximation of operations in the infinitesimal calculus by operations in the calculus of finite differences.

Exchange

to interchange the contents of two storage devices or locations.

Extract

to obtain certain digits from a word as may be specified, e.g., if the ten digit number 0000011100 is stored in a register, the computer can be instructed to "extract" the eighth digit from the left (in this case, a one) and correspondingly perform a certain action; to remove from a set of items of information all those items that meet some arbitrary condition.

FACTOR, SCALE

one or more coefficients used to multiply or divide quantities in a problem in order to convert them so as to have them lie in a given range of magnitude, e.g., plus one to minus one.

Feed, card

a mechanism which moves cards serially into a machine.

Ferromagnetics

in computer technology, the science that deals with the storage of information and the logical control of pulse sequences through the utilization of the magnetic polarization properties of materials to store binary information.

Field

a set of one or more characters (not necessarily all lying in the same word) which is treated as a whole; a set of one or more columns on a punched card consistently used to record similar information.

Field, card

a set of card columns fixed as to number and position into which the same unit of information is regularly entered.

File

a sequential set of items of information.

FIXED POINT

a notation or system of arithmetic in which all numerical quantities are expressed by a predetermined number of digits with the point implicitly located at some predetermined position; contrasted with floating point.

FLOATING POINT

a notation which takes into account varying locations of the decimal point (if radix is 10) or binary point (if radix is 2) by specifying separately for any given number its sign, its coefficient and its exponent relative to the radix, e.g., in floating point notation, the decimal number - 241,030,000 might be recorded as - , 2.4103,8, meaning - 2.4013 x 10^8.

FLOW CHART

a graphical representation of a sequence of operations, using symbols to represent the operations such as compute, substitute, compare, read, write, etc. A <u>flow chart</u> is a more detailed representation than a <u>block diagram</u>.

Force

to intervene manually in a routine and cause the computer to execute a jump instruction.

Generate

to produce a needed subroutine from parameters and skeletal coding.

Generator

a computer program which generates another program in coded form.

HARDWARE

the mechanical, magnetic, electronic and electrical devices from which a computer is fabricated; the assembly of material forming a computer.

HEAD

a device which reads, records or erases information in a storage medium; usually a small electromagnet used to read, write or erase information on a magnetic drum or tape; the set of perforating or reading fingers and block assembly for punching or reading holes in paper tape.

Hold

to retain information in one storage device after transferring it to another device, in contrast to "clear".

Ignore

an instruction requiring non-performance of what normally might be executed; a typewriter character indicating that no action is to be taken.

Information

an aggregation of data.

INPUT

the information which is transferred from a secondary or external source (e.g., paper tape) to the internal storage of the computer; given data for the problem to be solved, or raw data to be processed, by the computer.

Input unit

the device which takes into the computer information from outside the computer.

INSTRUCTION

a set of characters which defines an operation together with one or more addresses and which, as a unit, causes the computer to operate accordingly on the indicated quantities. The term "instruction" is preferred to the terms "command" and "order"; command is reserved for electronic signals; order is reserved for "the order of the characters" (implying sequence) or "the order of the interpolation", etc.

Instruction, breakpoint

an instruction which, if some specified switch is set, will cause the computer to stop.

Instruction, conditional breakpoint

a conditional jump instruction which, if some specified switch is set, will cause the computer to stop, after which either the routine may be continued as coded or a jump may be forced.

Instruction, multiple-address

see CODE, MULTIPLE-ADDRESS.

Instruction, one-address

an instruction consisting of an operation and exactly one address. The instruction code of a single-address computer may include both zero- and multi-address instructions as special cases.

Instruction, one-plus-one or three-plus-one address

a two- or four-address instruction, respectively, in which one of the addresses always specifies the location of the next instruction to be performed.

Instruction, transfer

a computer operational step in which a signal or set of signals specifies the location of the next operation to be performed and directs the computer to that operation (or instruction).

Instruction, two-, three-, or four-address

an instruction consisting of an operation code and 2, 3 or 4 addresses, respectively.

Instruction, zero-address

an instruction specifying an operation in which the locations of the operands are defined by the computer code, so that no address need be given explicitly.

Interlace

to assign successive storage locations to physically separated storage positions, e.g., on a magnetic drum or tape, usually for the express purpose of reducing access time.

INTERPRETER

an executive routine which, as the computation progresses, translates a stored program expressed in pseudo-code into computer code and performs the indicated operations, by means of subroutines, as they are translated.

Item

a set of one or more fields containing related information; a unit of correlated information relating to a single object; the contents of a single message.

JUMP

an instruction or signal which, conditionally or unconditionally specifies the location of the next instruction and directs the computer to that instruction. A jump is used to alter the normal sequence control of the computer. Under certain special conditions, a jump may be forced by manual intervention, in other words, a transfer of control is made to a specified instruction.

JUMP, CONDITIONAL

an instruction which will cause the proper one of two (or more) addresses to be used in obtaining the next instruction, depending upon some property of one or more numerical expressions or other conditions.

Key

a group of characters usually forming a field, utilized in the identification or location of an item; a marked lever manually operated for copying a character, e.g., typewriter, paper tape perforator, card punch manual keyboard, digitizer or manual word generator.

LANGUAGE, MACHINE

information recorded in a form which may be made available to a computer, e.g., punched tape may contain information available to a machine, whereas the same information in the form of printed characters on a page is not available to a machine; information which can be sensed by a machine.

Latency

in a serial storage system, the access time less the word time, e.g., the time spent waiting for the desired location to appear under the drum heads or at the end of an acoustic delay line.

LIBRARY, PROGRAM

a collection of standard and fully tested programs, routines, and subroutines by means of which many types of problems and parts of problems can be solved.

LINE PRINTER

a device for printing an entire line of characters across a page at one time as the paper feeds in one direction past a type bar or cylinder bearing all characters on a single element.

LOCATION, STORAGE

a storage position holding one computer word, usually designated by a specific address or a specific register.

LOGIC

the science that deals with the canons and criteria of validity in thought and demonstration; the science of the formal principles of reasoning; the basic

LOGIC (continued)

principles and applications of truth tables, gating, interconnection, etc., required for arithmetical computation in a computer.

Logic, symbolic

exact reasoning about relations using symbols that are efficient in calculation. A branch of this subject known as Boolean algebra has been of considerable assistance in the logical design of computer circuits.

LOOP

the repetition of a group of instructions in a routine.

Loop, closed

the repetition of a group of instructions indefinitely.

Malfunction

a failure in the operation of the hardware of a computer.

Matrix

in mathematics, an array of quantities in a prescribed form, usually capable of being subject to a mathematical operation by means of an operator or another matrix according to prescribed rules; an array of circuit elements, e.g., diodes, magnetic cores, relays, etc., which are capable of performing a specific function, e.g., conversion from one numerical system to another.

Memory

the term "storage" is preferred.

Merge

to produce a single sequence of items, ordered according to some rule (i.e., arranged in some orderly sequence), from two or more sequences previously ordered according to the same rule, without changing the items in size, structure or total number. Merging is a special case of collation.

Message

a group of words, variable in length, transported as a unit; a transported item of information.

MICROSECOND

a millionth part of a second.

MILLISECOND

a thousandth part of a second.

Mistake

a human blunder which results in an incorrect instruction in a program or in coding; an incorrect element of information; an incorrect manual operation.

Mnemonic

assisting, or intended to assist, memory; of or pertaining to memory, mnemonics is the art of improving the efficiency of the memory (in computers, storage).

Modifier

a quantity used to alter the address of an operand, e.g., the cycle index.

MODIFY

to alter, in an instruction, the address of the operand; to alter a subroutine according to a defined parameter.

Normalize

to adjust the exponent and mantissa of a floating-point result so that the mantissa lies in the prescribed standard (normal) range; standardize.

Notation

see **NUMBER SYSTEM.**

Number, operation

a number indicating the position of an operation or its equivalent subroutine in the sequence forming a problem routine. When a program is expressed in pseudo-code, each step is sometimes assigned an operation number.

Number, random

a set of digits constructed of such a sequence that each successive digit is equally likely to be any of n digits to the base n of the number.

Number system

numerical notation; positional notation; a systematic method for representing numerical quantities in which any quantity is represented approximately by the factors needed to equate it to a sum of multiples of powers of some chosen base n, e.g., in <u>decimal notation</u> in which n = 10, the number 371.426 represents $3(10)^2 + 7(10)^1 + 1(10)^0 + 4(10)^{-1} + 2(10)^{-2} + 6(10)^{-3}$; in <u>binary notation</u> in which n = 2, the number 1101.11 represents $1(2)^3 + 1(2)^2 + 0(2)^1 + 1(2)^0 + 1(2)^{-1} + 1(2)^{-2}$. In writing numbers, the base is sometimes indicated as a subscript (itself always in decimal notation) whenever there is any doubt about what base is being employed, e.g., $1101.11_2 = 13.75_{10}$; Binary, Ternary, Quatenary, Quinary, Octal, Decimal, Duodecimal, Sexadecimal (Hexadecimal) or Duotricenary Notation—notation using the base 2, 3, 4, 5, 8, 10, 12, 16 or 32 respectively.

Octal

pertaining to the number base of eight, e.g., in octal notation, octal 214 is $2(8)^2 + 1(8)^1 + 4(8)^0$ = decimal 140.

One address

single address; a system of machine instruction such that each complete instruction explicitly describes one operation and one storage location.

On-line operation

a type of system application in which the input data to the system is fed directly from the measuring devices and the computer results obtained during the progress of the event, e.g., a computer receives data from wind tunnel measurements during a run, and the computations of dependent variables are performed during the run enabling a change in the conditions so as to produce particularly desirable results.

Operand

any one of the quantities entering or arising in an operation. An operand may be an argument, a result, a parameter, or an indication of the location of the next instruction.

Operation

a defined action; the action specified by a single computer instruction or pseudo-instruction; an arithmetical, logical or transferal unit of a problem, usually executed under the direction of a subroutine.

Operation, arithmetical

an operation in which numerical quantities form the elements of the calculation, e.g., addition, subtraction, multiplication, division.

Operation, computer

the electronic action of hardware resulting from an instruction; in general, computer manipulation required to secure computed results.

Operation, fixed-cycle

a type of computer performance whereby a fixed amount of time is allocated to an operation; synchronous or clocked type arrangement within a computer in which events occur as a function of measured time.

Operation, logical

an operation in which logical (yes or no) quantities form the elements being operated upon, e.g., comparison, extraction. A usual requirement is that the value appearing in a given column of the result shall not depend on the values appearing in more than one given column of each of the arguments.

Operation, parallel

the flow of information through the computer or any part of it using two or more lines or channels simultaneously. Contrasted with serial operation.

Operation, real-time, on-line, simulated

the processing of data in synchronism with a physical process in such a fashion that the results are useful to the physical operation.

Operation, red-tape

an operation which does not directly contribute to the result, i.e., arithmetical, logical and transfer operation used in modifying the address section of other instructions in counting cycles, in rearranging data, etc.

Operation, serial

the flow of information through the computer or any part of it in time sequence, using only one digit, word, line or channel at a time. Contrasted with parallel operation.

Operation, transfer

an operation which moves information from one storage location or one storage medium to another, e.g., read, record, copy, transmit, exchange. Transfer is sometimes taken to refer specifically to movement between different media; storage to movement within the same medium.

Operation, variable cycle

computer action in which any cycle of action or operation may be different lengths. This kind of action takes place in an asynchronous computer.

OPERATOR

the person who actually manipulates the computer controls, places information media into the input devices, removes the output, presses the start button, etc.; a mathematical symbol which represents a mathematical process to be performed on an associated function.

Or-operator

a logical operator which has the property such that if P and Q are two statements, then the statement "P or Q" is true or false precisely according to the following table of possible combinations:

P	Q	P or Q
false	false	false
false	true	true
true	false	true
true	true	true

The or-operator is often represented by the plus sign, e.g., P + Q.

Order

a defined successive arrangement of elements or events.

OUTPUT

information transferred from the internal storage of a computer to secondary or external storage; information transferred to any device exterior

OUTPUT (continued)

to the computer; the results of the computation or processing performed by the computer.

Output block

a portion of the internal storage reserved primarily for receiving, processing and transmitting data which is to be transferred out.

Output unit

the unit which delivers information outside the computer in acceptable language.

OVERFLOW

in an arithmetic operation, the generation of a quantity beyond the capacity of the register or location which is to receive the result; over capacity; the information contained in an item which is in excess of a given amount.

Pack

to combine several different brief items of information into one word by using different sets of digits for each item.

Parallel

handled simultaneously in separate facilities; operating on two or more parts of a word or item simultaneously; contrasted with serial.

PARAMETER

in a subroutine, a quantity which may be given different values when the subroutine is used in different main routines or in different parts of the same main routine, but which usually remains unchanged throughout any one such use; in a generator, a quantity used to specify input-output devices, to designate subroutines to be included, or otherwise to describe the desired routine to be generated.

Parameter, preset

a parameter incorporated into a subroutine during input.

Parameter, program

a parameter incorporated into a subroutine during computation. A program parameter frequently comprises a word stored relative to either the subroutine or the entry point and dealt with by the subroutine during each reference. It may be altered by the routine and/or may vary from one point of entry to another.

Patch

a section of coding inserted into a routine to correct a mistake or to alter the routine; explicitly transferring control from a routine to a section of coding and back again.

Plotting board or plotter

a unit capable of graphically presenting information; analog curve or point tracer.

Plug board

a removable panel containing an ordered array of terminals which may be interconnected by short electrical leads according to a prescribed pattern and hence designating a specific program. The entire panel, pre-wired, may be inserted for different programs.

Point

the dot that marks the separation between the integral and fractional parts of a number, i.e., between the coefficients of the zero and the minus one powers of the number base. For a number system using the base two, it is called the binary point; for base 10, the decimal point; etc.

Post mortem

a routine which, either automatically or on demand, prints information concerning the contents of the registers and storage locations at the time the routine stopped, in order to assist in locating coding mistakes.

Precision

the degree of exactness with which a quantity is stated; a relative term often based on the number of significant digits in a measurement. See also ACCURACY.

PRECISION, DOUBLE

retention of twice as many digits of a number as the computer normally handles, e.g., a computer for which the basic word consists of ten decimal digits is called upon to handle twenty decimal digit numbers by keeping track of the ten-place fragments.

Pre-store

to set an initial value for the address of an operand or a cycle index; to restore; to store a quantity in an available or convenient location before it is required in a routine.

PROGRAM

a plan for the solution of a problem. A complete program includes plans for the transcription of data, coding for the computer, and plans for the absorption of the results into the system. The list of coded instructions is called a coded program or a routine; to plan a computation or process from the asking of a question to the delivery of the results, including the integration of the operation into an existing system. Thus programming consists of planning and coding, including numerical analysis, systems analysis, specification of printing formats, and any other functions necessary to the integration of a computer in a system.

Program step

a step in a program, usually one instruction.

PROGRAMMER

a person who prepares instruction sequences without necessarily converting them into computer code.

Pseudo-code

an arbitrary code, independent of the hardware of the computer, which must be translated into computer code.

Pulse

a change in the intensity or level of some medium, usually over a relatively short period of time, e.g., a shift in electric potential of a point for a short period of time compared to the time period, i.e., if the voltage level shifts from -10 to +20 volts with respect to ground for a period of two microseconds, it is said that the point receives a 30 volt 2 microsecond pulse.

Pulse code

sets of pulses to which particular meanings have been assigned; the binary representations of characters.

Punch position

the location of the row in a columnar card, e.g., in an 80-column card, the rows or "punch positions" may be 0 to 9 or "X" and "Y" corresponding to positions 11 and 12.

Punch, summary

a card handling machine which may be electrically connected to another machine, e.g., tabulator, and which will punch out on a card the information produced, calculated, or summarized by the other machine.

Punching, rate of

number of cards, characters, blocks, fields or words of information placed in the form of holes on cards or tape per unit of time.

Range

all the values which a function may have.

RATIO, OPERATING

the ratio obtained by dividing the number of hours of correct machine operation by the total hours of scheduled operation, e.g., on a 40 hour week scheduled operation, if 3 hours of preventive maintenance is required and 1.1 hours of unscheduled down-time occurs, then the operating ratio is (40 - 4.1)/40 which is equivalent to a 90 per cent operating ratio.

READ

to copy, usually from one form of storage to another, particularly from external or secondary storage to internal storage; to sense the presence of information on a recording medium.

Reading, rate of

number of characters, words, fields, blocks or cards sensed by an input sensing device per unit of time.

Real time

the performance of a computation during the actual time that the related physical process transpires in order that results of the computations may be useful in guiding the physical process.

Record

a listing of information, usually in printed or printable form; one output of a compiler consisting of a list of the operations and their positions in the final specific routine and containing information describing the segmentation and storage allocation of the routine; to copy or set down information in reusable form for future reference; to make a transcription of data by a systematic alteration of the condition, property or configuration of a physical medium, e.g., placing information on magnetic tape or a drum by means of magnetized spots.

REGISTER

the hardware for storing one or more computer words.

Register, circulating

a register or memory device consisting of a means for delaying information and a means for regenerating and reinserting the information into the delaying means.

Register, control

the register or storage unit which stores the current instruction governing a computer operation; an instruction register.

REGISTER, INDEX

a register whose contents are used to modify automatically addresses incorporated in instructions just prior to their execution, the original instruction remaining intact and unmodified in storage. It may either be built in the hardware and circuitry of the computer or be simulated by the program.

Register, program

a register in the control unit which stores the current instruction of the program and controls computer operation during the execution of the instruction; control register.

Repetition, rate of pulse

the number of electric pulses per unit of time experienced at a point in the computer, usually the maximum, normal or standard pulse rate.

Representative circulating time

a measure of the speed performance of a computer. One method uses one-tenth of the time required to perform nine complete additions and one complete multiplication. A complete addition or a complete multiplication time includes the time required to procure two operands from storage, perform the operation and store the result and the time required to select and execute the required number of instructions to do this.

Rerun

to repeat all or part of a program on a computer.

Rerun point

that stage of a computer run at which all information pertinent to the running of the routine is available either to the routine itself or to a rerun routine in order that a run may be reconstituted.

Reset

to return a device to zero or to an initial or arbitrarily selected condition.

Restore

to return a cycle index, a variable address, or other computer work to its initial or preselected value.

Return

to go back to a specific, planned point in a program, usually when an error is detected, for the purpose of rerunning the program. Rerun points are usually three to five minutes apart to avoid long periods of lost computer time.

Rewind

to return a tape to its beginning.

Rollback

equivalent to "rerun" when referring to tape-sequenced computers; to recapture tape-inscribed data.

Round-off

to change a more precise quantity to a less precise one, according to some rule.

ROUTINE

a set of coded instructions arranged in proper sequence to direct the computer to perform a desired operation or series of operations.

ROUTINE, DIAGNOSTIC

a specific routine designed to locate either a malfunction in the computer or a mistake in coding.

Routine, executive

a set of coded instructions designed to process and control the other sets of coded instructions; a set of coded instructions used in realizing "automatic coding"; a master set of coded instructions.

Routine, floating-point

a set of coded instructions arranged in proper sequence to direct the computer to perform a specific set of operations which will permit floating-point operation, e.g., enable the use of a fixed-point machine to handle information on a floating-point basis; floating-point routines are usually used in computers which do not have built-in floating-point circuitry, in which case floating-point operation must be programmed.

Routine, general

a routine expressed in computer code designed to solve a class of problems, specializing to a specific problem when appropriate parametric values are supplied.

Routine, minimal latency

especially in reference to serial storage systems, a routine so coded, by judicious arrangement of data and instructions in storage, that the actual latency is appreciably less than the expected random-access latency.

Routine, rerun

a routine designed to be used in the wake of a computer malfunction or a coding or operating mistake to reconstitute a routine from the last previous rerun point; roll back routine.

Routine, sequence checking

a routine which checks every instruction executed, printing certain data, e.g., to print out the coded instructions with addresses, and the contents of each of several registers, or it may be designed to print out only selected data, such as transfer instructions and the quantity actually transferred.

Routine, service

a routine designed to assist in the actual operation of the computer. Tape comparison, block location, certain post mortems, and correction routines fall in this class.

Routine, specific

a routine expressed in computer coding designed to solve a particular mathematical, logical or data-handling problem in which each address refers to explicitly stated registers and locations.

Routine, test

a routine designed to show whether a computer is functioning properly or not.

RUN

one performance of a program on a computer; performance of one routine, or several routines automatically linked so that they form an operating unit, during which manual manipulations are not required of the computer operator.

SCALE

to alter the units in which all variables are expressed so as to bring all magnitudes within the capacity of the computer or routine at hand, without overflow.

Segment

to divide a routine into parts each consisting of an integral number of subroutines, each part capable of being completely stored in the internal storage and containing the necessary instructions to jump to other segments; in a routine too long to fit into internal storage, a part short enough to be stored entirely in the internal storage and containing the coding necessary to call in and jump automatically to other segments.

Selector

a device which interrogates a condition and initiates a particular operation according to the interrogation report.

Sense

to examine, particularly relative to a criterion; to determine the present arrangement of some element of hardware, especially a manually set switch; to read holes punched in cards to tape.

Sentinel

a symbol marking the beginning or the end of some element of information such as a field, item, block, tape, etc.; a tag.

Sequencer

a machine which puts items of information into a particular order, e.g., it will determine whether A is greater than, equal to, or less than B, and sort or order accordingly.

Serial

handle one after another in a single facility, such as transfer or store in a digit-by-digit time sequence.

Shift

to move the characters of a unit of information column-wise right or left. For a number, this is equivalent to multiplying or dividing by a power of the number base.

Shift, arithmetic

to multiply or divide a quantity by a power of the number base, e.g., binary 1011 represents decimal 11, therefore two arithmetic shifts to the left is binary 101100 which represents decimal 44.

Shift, cyclic

a shift in which the digits dropped off at one end of a word are returned at the other in a circular fashion; logical, non-arithmetic or circular shift.

SIMULATION

the representation of physical systems and phenomena by computers, models or other equipment.

Skip

an instruction to proceed to the next instruction.

Sort

to arrange items of information according to rules dependent upon a key or field contained in the items.

Stacker, card

a mechanism that accumulates cards in a bin after they have passed through a machine operation.

Standardize

to adjust the exponent and mantissa of a floating-point result so that the mantissa lies in the prescribed normal range; normalize.

STORAGE

any device into which units of information can be copied, which will hold this information, and from which the information can be obtained at a later time; devices such as plugboards, which hold information in the form of arrangements of physical elements, hardware or equipment; the erasable storage in any given computer.

STORAGE, BUFFER

a synchronizing element between two different forms of storage, usually between internal and external; an input device in which information is assembled from external or secondary storage and stored ready for transfer to internal storage; an output device into which information is copied from internal storage and held for transfer to secondary or external storage. Computation continues while transfers between buffer storage and secondary or internal storage or vice versa take place.

Storage, circulating

a device using a delay line, or unit which stores information in a train or pattern of pulses, where the pattern of pulses issuing at the output end are sensed, amplified, reshaped and reinserted in the delay line at the input end.

Storage, dynamic

storage such that information at a certain position is moving in time and so is not always available instantly, e.g., acoustic delay line, magnetic drum; circulating or recirculating of information in a medium.

Storage, electrostatic

a device possessing the capability of storing changeable information in the form of charged or uncharged areas on the screen of a cathode ray tube.

Storage, erasable

media which may hold information that can be changed, i.e., the media can be reused, e.g., magnetic tape, drum or cores.

STORAGE, EXTERNAL

storage facilities divorced from the computer itself but holding information in the form prescribed for the computer, e.g., magnetic tapes, punched paper tape, punched cards.

STORAGE, INTERNAL

storage facilities forming an integral physical part of the computer and directly controlled by the computer; the total storage automatically accessible to the computer.

Storage, magnetic

any storage system which utilizes the magnetic properties of materials to store information.

Storage, non-erasable

media used for containing information which cannot be erased and reused, such as punched paper tape and punched cards.

Storage, non-volatile

storage media which retain information in the absence of power and which may be made available upon restoration of power, e.g., magnetic tapes, drums or cores.

Storage, secondary

storage facilities not an integral part of the computer but directly connected to and controlled by the computer such as magnetic tapes.

STORAGE, TEMPORARY

internal storage locations reserved for intermediate and partial results.

Storage, volatile

storage media such that if the applied power is cut off, the stored information is lost, e.g., acoustic delay lines, electrostatic tubes.

STORAGE, WORKING

a portion of the internal storage reserved for the data upon which operations are being performed.

Storage, zero-access

storage for which the latency (waiting time) is negligible at all times.

STORE

to transfer an element of information to a device from which the unaltered information can be obtained at a later time.

SUBROUTINE

the set of instructions necessary to direct the computer to carry out a well defined mathematical or logical operation; a subunit of a routine. A subroutine is often written in relative or symbolic code even when the routine to which it belongs is not.

Subroutine, closed

a subroutine not stored in its proper place in the linear operational sequence, but stored away from the routine which refers to it. Such a subroutine is entered by a jump, and provision is made to return, i.e., to jump back to the proper point in the main routine at the end of the subroutine.

Subroutine, open

a subroutine inserted directly into the linear operational sequence, not entered by a jump. Such a subroutine must be recopied at each point that it is needed in a routine.

Substitute

to replace an element of information by some other element of information.

Switch, program

in flow charting, a transfer operation controlled by a decision made at some prior and remote point in the program.

Symbol, logical

a symbol used to represent a logical element graphically.

SYSTEM

an assembly of components united by some form of regulated interaction; an organized whole.

Tabulator

a machine which reads information from one medium, e.g., cards, paper tape, magnetic tape, etc., and produces lists, tables and totals on separate forms or continuous sheets of paper.

Tag

a unit of information whose composition differs from that of other members of the set so that it can be used as a marker or label; a sentinel.

Tape, magnetic

a tape or ribbon of any material impregnated or coated with magnetic material on which information may be placed in the form of magnetically polarized spots.

Tape, program

a tape which contains the sequence of instructions required for solving a problem and which may be read by the computer.

Test, crippled leap-frog

a variation of the leap-frog test, modified so that it repeats its tests from a single set of storage locations rather than a changing set of locations.

Test, leap frog

a program designed to discover computer malfunction, characterized by the property that it performs a series of mathematical or logical operations on one group of storage locations, transfers itself to another group of storage locations, checks the correctness of the transfer, then begins the series of operations over again. Eventually all storage positions will have been occupied.

Time, idle

time in which machine is believed to be in good operating condition and attended by service engineers but not in use on problems. To verify that the computer is in good operating condition, machine tests of the leap-frog variety may be made.

TIME, PRODUCTION

good computing time, including occasional duplication of one case for a check or rerunning of the test run and any reruns caused by misinformation or faulty data.

Time, standby, unattended

time in which the machine is in an unknown condition and not in use on problems. Includes time in which the machine is known to be defective and work is not being done to restore it to operating condition. Includes breakdowns which render it unavailable due to outside conditions (power, outages, etc.).

Time, system improvement

all machine down time needed for the installation and testing of new components and machine down time necessary for modification of existing components.

Track

in a serial magnetic storage element, a single path containing a set of pulses.

Transcribe

to copy, with or without translation, from one external storage medium to another.

Transfer

to copy, exchange, read, record, store, transmit, transport, or write data; to change control; to jump to another location.

TRANSFER, CONDITIONALLY

to copy, exchange, read, record, store, transmit or write data or to change control or jump to another location according to a certain specified rule or in accordance with a certain criterion.

Transfer, parallel

a system of data transfer in which the characters of an element of information are transferred simultaneously over a set of paths.

Transfer, serial

a system of data transfer in which the characters of an element of information are transferred in sequence over a single path in consecutive time positions.

TRANSFER, UNCONDITIONAL

an instruction which causes the subsequent instruction to be taken from an address which is not the next one in sequence in a digital computer which ordinarily obtains its instructions serially from an ordered sequence.

Transform

to change information in structure or composition without altering the meaning or value; to normalize, edit or substitute.

Translate

to change information (e.g., problem statements in pseudo-code, data or coding) from one language to another without significantly affecting its meaning.

Transmit

to reproduce information in a new location replacing whatever was previously stored and clearing or erasing the source of the information.

Transport

to convey as a whole from one storage device to another.

Truncate

to drop digits of a number or terms of a series thus lessening precision, e.g., the number 3.14159265 is truncated to five figures in 3.1415 whereas it may be rounded to 3.1416.

Unpack

to decompose packed information into a sequence of separate words or elements.

Verifier

a device on which a manual transcription can be verified by comparing a retranscription with it character by character as it is being retranscribed.

WORD

a set of characters which occupies one storage location and is treated by the computer circuits as a unit and transported as such. Ordinarily a word is treated by the control unit as an instruction, and by the arithmetic unit as a quantity. Word lengths are fixed or variable depending on the particular computer involved.

WORD TIME

especially in reference to words stored serially, the time required to transport one word from one storage device to another.

WRITE

to transfer information to an output medium; to copy, usually from internal storage to external storage; to record information in a register, location or other storage device or medium.

ZERO SUPPRESSION

the elimination of non-significant zeros to the left of the integral part of a quantity before printing operations are initiated; a part of editing.

Zone

a portion of internal storage allocated for a particular function or purpose; any of the three top positions of 12, 11 and 0 on a punch card. In these zone positions, a second punch can be inserted so that with punches in the remaining positions 1 to 9, alphabetic characters may be represented.

Respectfully submitted,

James W. Conlon
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HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

USE OF MATHEMATICAL MODELS IN ESTIMATING TRAVEL

Alan M. Voorhees,[1] M. ASCE

On the bases of relationship developed from numerous O-D studies that have been conducted throughout the country, it is now feasible to estimate urban travel patterns by mathematical procedures. These techniques can be used to predict highway volumes as well as number of passengers that will use a specific mass transit improvement. Tests of these procedures indicate a high degree of reliability.

The development of any new techniques usually bring along with it some new jargon. In the field of traffic planning, the new phrase is "models." Had these techniques been developed twenty or thirty years ago, they would have simply been called "formulas," but to conform to other professional groups, these procedures are referred to as mathematical models.

A model, in a descriptive sense, utilizes certain mathematical techniques which involve various steps and equations. More simply, it can be defined as a mathematical statement of observed relationships. For example, surveys of shopping habits have revealed that shoppers follow certain patterns that can be predicted mathematically. With such mathematical procedures, it becomes possible to estimate or forecast where people will shop. Since these techniques deal with travel habits, they are known as traffic models.

Now it becomes apparent from the analysis of O-D studies which have been done by the Bureau of Public Roads and others, that traffic movement in urban areas can be simulated by an application of a traffic model.(1) In other words, if you know certain factors about a community, such as the number of people that live and work in various zones, as well as the car ownership in these zones, it is possible by following certain mathematical procedures to estimate the O-D of urban travel.

To understand a traffic model, an examination of how a model could be applied might be helpful.

Note: Discussion open until May 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2280 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. HW 4, December, 1959.

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The method of synthesizing traffic generally is carried out in two steps; first, the frequency and mode of travel of individual trips was determined and then, the destination of these trips was estimated.

The frequency of these trips naturally depend upon individual needs and desires. For instance, an insurance salesman undoubtedly travels more each day than a typical industrial employee. The mode of travel either party chooses will depend on the availability of an automobile and/or the adequacy of public transportation services. The destination of these trips will depend on the distribution of land uses—the location of shopping centers, industrial and commercial areas, and residential neighborhoods. In a way, it might be said that individual travel patterns reflect the opportunities that are afforded.

Trip Frequency

In advance of estimating trip frequency, a decision must be made on the number of trip purposes which should be employed. At the present time there is no general agreement on this, however, in the Baltimore Transportation Study four trip purposes were used.

1. Work Trips—to and from work—does not include repair runs and salesmen trips.
2. Commercial Trips—to and from commercial areas including trip for personal business, shopping, and dining or entertaining.
3. Social Trips—to residential areas including trips to school and visiting friends.
4. Non-Home Based Trips—consist, for example, of salesmen in door-to-door traveling or housewives shopping from store to store.

In figuring trip frequency in general, commercial and social trip frequency was based on car ownership. For example, for every 1,000 cars garaged in a residential area, 800 commercial and 400 social auto trips commenced daily and of these 40 commercial and 15 social trips started at the peak hour. (The Washington, D. C. Transportation Study revealed about the same number of trips return during the peak hour.)

Calculating work trip frequency involved a more complicated procedure since the number of work trips is related to employment rather than to car ownership. In Hartford this was done first by estimating the number of workers usually departing daily from a residential district by some form of transportation (85 per cent of labor force). Then the number of transit work trips starting from a residential area was determined by using Table 1. The total number of transit trips should then be calculated and compared with the number of transit trips made in the area each day. (This should be about one quarter of the revenue passengers since about one half of all transit trips are related to work.) If the comparison is not favorable, a comparison should be made on a sectional basis of the number of buses in and out of an area with the estimated number of transit work trips. Then appropriate adjustments should be applied.

The number of work trips made by auto can be determined by subtracting the transit work trips from the number of workers departing by some form of transportation. To figure the number of automobile driver work trips starting from each area, the number going by auto should be corrected for car pooling. See Table II. (To simplify computation for peak hour travel, usually it is assumed that all work trips are returning home at the evening peak hour.

Table I

Percentage of All Work Trips Made by Transit

Cars per 1000 persons	Net Land per Family - in sq. feet					
	10,000	5,000	2,500	1,200	600	300
500	5%	7%	11%	19%	33%	65%
450	7	9	13	21	35	67
400	9	11	15	23	37	69
350	11	13	17	25	39	71
300	13	15	19	27	41	73
275	14	16	20	28	42	74
250	15	17	21	29	43	75
225	16	18	22	30	44	76
200	17	19	23	31	45	77
175	18	20	24	32	46	78
150	19	21	25	33	47	79
125	20	22	26	34	48	80

Based on Highway Traffic Estimation, Eno Foundation and Data from the Chicago Area Transportation Study.

The frequency of non-home based trips can be established in several ways. One way is to assume that 1,200 trips start each day for every 1,000 cars and 30 commence at the peak hour. Furthermore, the number of trips starting from each zone is in direct portion to the number of people employed in each zone plus 5 times the retail employees—this is in line with the fact that about half of such trips start from commercial areas and the rest are related to place of employment.

To keep the technique simple, usually only two types of transit trips are considered—work trips and miscellaneous trips. The frequency of miscellaneous transit trips may be assumed to equal that of work trips, and thus it is possible to estimate all transit trips from Table I.

Trip Destination

The destinations of these various types of trips can be accomplished by several methods. In Baltimore the so-called gravity model was applied. Essentially, this model follows Newton's law of gravity and states that all trips emanating from an area are attracted or "pulled" to various land uses. The strength of this pull is associated directly with the size of land use development and indirectly associated with the distance (or travel time) between the land use and the starting point of the trip.(2)

Table II

Relationship Between Persons Per Car and Car Ownership for Work Trips

Cars per 1,000 persons	Persons Per Car
100	1.65
150	1.52
200	1.46
250	1.40
300	1.33
350	1.30
400	1.27
450	1.23
500	1.20

Under this concept for transit travel, transit time between zones is used; while auto-travel time between zones is applied for private-vehicle trips.

Of course, transit users tend to adjust their traveling habits to accord with mass public transportation service. Travel time between zones depends on transit service. The auto user, being more versatile is influenced by the travel time permitted by the highway network. Since most auto and transit travel occurs in the off-peak hours, midday hours were selected for study.

To appropriately select suitable factors to express the "size" of the attracting land use for work trips, the total number of people employed in each area is usually analyzed. For commercial trips, retail employment for each zone may be examined to reflect the size of the attractor. This index is often selected as a matter of convenience, for it may be easy to estimate retail employment. In considering social trips, the number of people living in each area is generally chosen to indicate attractor size.

For non-home based trips, employment plus 5 times retail employment may be employed. The exact factor or factors that should be used will depend upon the availability of statistical data and the appropriateness of such factors.

Using employment statistics and population figures, made it easier to link the survey with the economic-base data for the area. From experience gained in New Haven, it appears that the size of the attractor is more effectively expressed in terms of employment and population rather than in acreage of various land uses.

The effects of travel time on trip destination may be measured by a series of factors like those shown in Table III. These travel-time factors are based on research that has shown that different factors are necessary for various

Table III

Travel Time Factors

Travel Time In Minutes	Relative Frequency of Trips by Type Work	Social	Commercial	Non-Home-Based
2	4.00	5.00	8.0	8.0
3	2.86	3.33	7.0	7.0
4	2.28	2.50	6.0	6.0
5	1.90	2.00	4.0	4.0
6	1.60	1.62	2.7	2.7
7	1.40	1.42	2.0	2.0
8	1.21	1.25	1.5	1.5
9	1.11	1.11	1.2	1.2
10	1.00	1.00	1.0	1.0
11	0.93	.91	.80	.80
12	.86	.83	.68	.68
13	.80	.77	.57	.57
14	.75	.71	.50	.44
15	.70	.67	.44	.40
16	.66	.62	.40	.35
17	.62	.59	.35	.32
18	.59	.55	.32	.28
19	.56	.52	.28	.25
20	.53	.50	.25	.22
21	.50	.46	.23	.19
22	.47	.43	.21	.16
23	.44	.40	.20	.13
24	.41	.37	.18	.10
25	.39	.34	.16	.08
26	.36	.32	.15	.06
27	.33	.30	.14	.04
28	.31	.28	.13	.02
29	.27	.26	.12	.01
30	.25	.25	.11	-
32	.21	.21	.10	-
34	.18	.18	.08	-
36	.16	.16	.07	-
38	.14	.14	.07	-
40	.12	.12	.07	-
45	.07	.07	.05	-
50	.04	.04	.03	-
60	.01	.01	.01	-

trip types.(3) Such factors indicate the effect that travel time has on the frequency of trips between areas.

As an example of the significance of these factors: an industrial zone two minutes from a residential area attracts four times as many work trips as a comparable industrial zones ten minutes distant. See Table III.

To calculate the destination of work trips beginning in a residential zone, the appropriate time factor is multiplied by the number of people employed in various zones. Work trips are subsequently distributed to each employment zone in proportion to that zone's product and the sum of the product for all zones. (An example of this process is included at the end of this article.)

This same general technique may be used in studying truck travel in an urban area, for various studies have shown that the non-home-based trip

pattern is fairly comparable to truck movement patterns in urban areas.

When the gravity model is employed to distribute work trips, the distribution must be brought into balance. For example, if, in its application, too many trips were allocated to a particular employment center, they should be adjusted to conform to the estimated number of auto and transit trips destined to a center. This can be achieved by multiplying the trips to the center of an appropriate adjustment factor. These corrective measures should be made to work trips only.

To figure the number of auto or transit work trips destined to an area, Table I can be used. This reflects the fact that transit usage, in an area of low car-ownership, naturally will be high. Conversely, in an area of high car-ownership transit travel will be low. Hence, Table I can be used to indicate this relationship, and applied in developing the necessary calculations.

This model can also be modified for trips to the downtown area. This may be necessary to adjust for the difference in relationships between home and place of employment for different occupational classes. (From experience in other cities it would appear that this correction is necessary only for trips to the downtown area.[4])

The correction for downtown trips is not complex. It involved an investigation of the model's degree of error regarding downtown trips. This can be achieved by analyzing a previous transportation study for the CBD such as a parking study. (See Fig. 1)

Check the Results

Even though the techniques that have been described are based on considerable research, a check of the results should be carried out. Some of the checks that can be made are screen line comparison, employees' residence survey and parking studies. In Baltimore, four screen lines were created which divided the metropolitan area into large segments. Traffic was counted as it crossed the screen lines and then compared with the traffic estimates obtained from the model. As indicated in Table IV, the screen line checks were usually within 10 per cent of the actual traffic counts. Further, similar checks were carried out for mass transit and the results indicate a comparable degree of accuracy.

Table IV

Screen Line Checks of the Baltimore 1958 Traffic Estimates

	24 Hours			Peak Hour		
Screen Line	Actual	Estimate	Estimate As Per Cent of Actual	Actual	Estimate	Estimate As Per Cent of Actual
A	487,500	457,200	94	40,100	40,300	100
B	384,900	399,100	102	35,400	32,900	93
C	323,200	365,700	112	30,200	33,700	111
D	254,400	280,900	110	23,000	24,100	105

Besides the screen-line checks, information was amassed on employees' residences in several industrial plants. This information was checked against estimates developed by the gravity model. As indicated in Table V, the technique accurately portrays the proportion of trips within specific travel

times of the employment area. In making this comparison on a zone-to-zone basis there was a greater deviation between the actual and theoretical estimate. For example, when zone-to-zone volumes were 100, the root-mean square error was around 50 per cent; for volumes of 1000, the error was about 20 per cent; for volumes of 10,000, the error was about 10 per cent.*

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*Root-mean square error means that two thirds of the time this error will be less than specified.

FIGURE I

RESIDENTIAL AREAS WHERE OBSERVED TRAVEL TO DOWNTOWN BALTIMORE VARIED FROM TRAFFIC MODEL

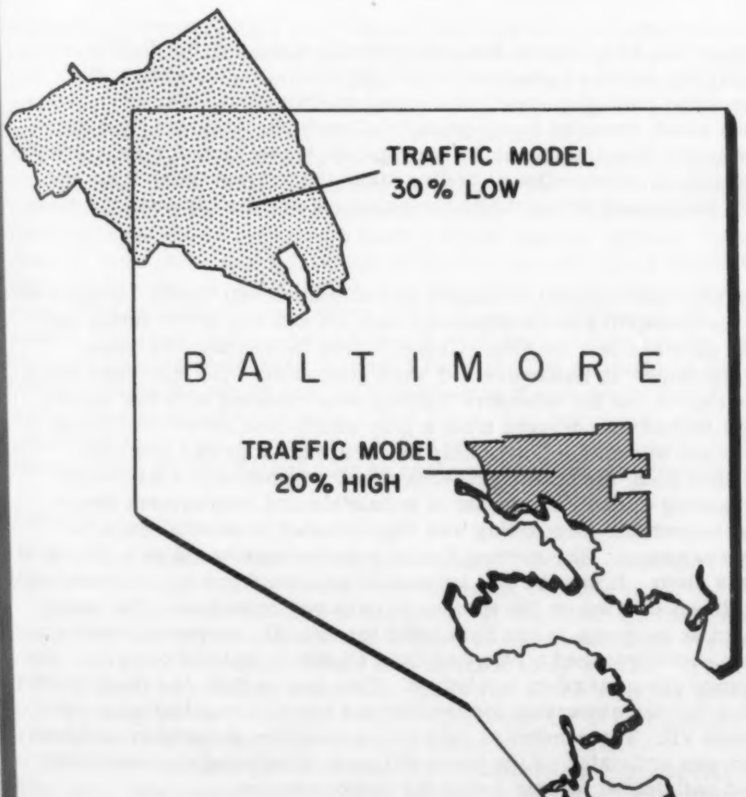


Table V

Comparison of Actual and Estimated Numbers of Trips, by Travel Time from 3 Manufacturing Plants, Baltimore: 1958.

Time of Trip in Minutes	Percentage of Trips Within Time Periods					
	Westinghouse		Bendix		Glen L. Martin	
	Actual	Estimate	Actual	Estimate	Actual	Estimate
0 - 10	42	37	32	29	-	-
0 - 20	64	60	74	76	24	17
0 - 30	82	78	94	94	71	64
0 - 40	97	98	100	100	93	94
Over 0	100	100	100	100	100	100

This series of checks indicated that, statistically speaking, the Baltimore traffic model was about as accurate as a 5 per cent home-interview study.

An interesting historical check was based on data from 1926, 1946, and 1958 studies which revealed home-work relationships. For this time span the gravity model was suitable if the appropriate travel time for each era was used, an especially extraordinary finding since the average work trips had become 40% longer and travel times have changed drastically over the years.

Projections

In projecting future travel, it should be recognized that traffic patterns depend upon the transportation alternatives that are offered to the public and the land use patterns that develop. Hence, it may be necessary to make several projections. In Baltimore two were completed. The first was based upon a plan that called for extensive highway improvement with few transit changes; the second was derived from a plan which entailed several rapid transit lines and the completion of only the interstate highway systems.

For the first plan, the traffic projections were based on the Baltimore Regional Planning Council's forecast of population and employment distribution. Car-ownership forecasting was implemented in several ways for comparative purposes. The method finally selected was based on a Bureau of Public Roads study. It showed that income of household and type of residential area had a direct bearing on the number of cars per household. The study also revealed an increase in car ownership for specific residential areas until the income level reached a range of from $8,000 to $10,000 per year. Beyond this range car ownership leveled off. This means that, in effect, there was a ceiling for car ownership for the various types of residential areas (consult Table VI). The number of cars which would be garaged in each residential zone was estimated on the basis of trends of existing car-ownership patterns and anticipated income levels for various zones.

The existing travel times between zones were not used in projecting travel for the first plan; rather travel times resulting from the development of an

Table VI

Ceiling for Car Ownership per Household

Residence Type	Autos Per Household
Single Family	
new area	1.6
old area	1.0
Two Family	
new area	1.2
old area	0.9
Row House	
good transit & poor parking	0.4
good transit & good parking	0.6
poor transit & good parking	1.0
Elevator Apartments	
good transit & poor parking	0.2
good transit & good parking	0.4
poor transit & good parking	0.6

extensive freeway system were used. This was done to reflect the fact that improved highway facilities tend to increase travel length, as revealed by the historical checks previously mentioned. To sum up, the traffic forecasts measured the effects of anticipated increases in population and employment, car ownership, and expected increases in auto speeds.

The projection of traffic in the transit plan was accomplished on a somewhat similar basis. Car-ownership patterns in the vicinity of proposed rapid transit lines were adjusted in accordance with Table VI. The auto-travel times between zones reflected a more limited freeway system. Certain changes were made in the land use forecasts, specifically, a 20 per cent employment increase in the CBD. A new set of auto and transit patterns was formulated by using these criteria. But, it was recognized that a certain portion of the population probably would shift from auto to transit travel in the event rapid transit lines became a reality. The estimate of the volume of this shift to rapid transit was calculated using the curve in Fig. 2. The curve was applied to only 75 per cent of auto trips, that percentage of trips for which autos were not necessary. It was possible to forecast the traffic and auto patterns for the second plan by completion of the latter procedure.

Example

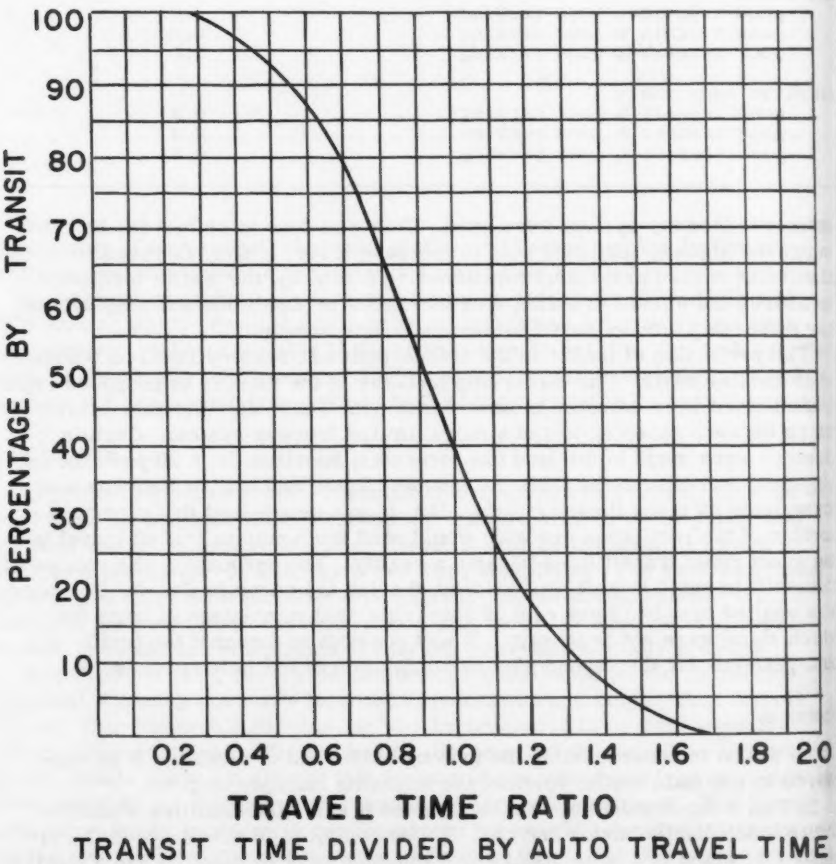
To assist in understanding the gravity model and to visualize it as employed to estimate traffic volume, the following example is given.

In Fig. 3 the residential area designated R has 1,000 families within its limits, each family having one car. Three commercial areas are in the vicinity C1, which is a mile distant or 5 minutes away by auto. It has a total of 100 employed in retailing activities. C2 is two miles away, or about 10 minutes away by car, with 200 retail employees. C3 is four miles away, or 20 minutes away by car, with 400 employees in retailing.

Consistent with the previous discussion concerning commercial trip frequency, this means that 800 trips per day would start from residential area R. Based on calculations shown in Fig. 3, 456 trips would be made to C1; 232 trips to C2; and 112 trips to C3.

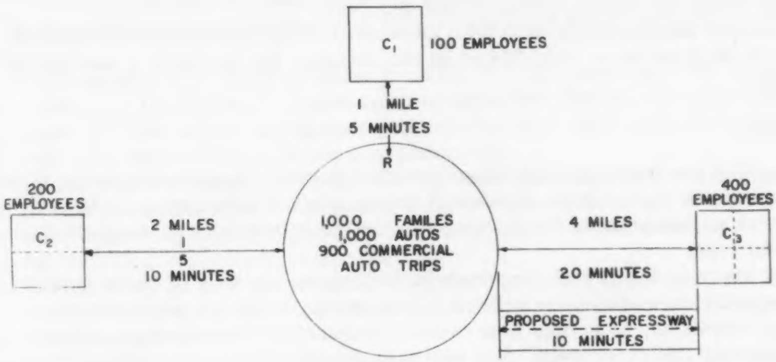
FIGURE 2

TRANSIT ASSIGNMENT CURVE



BASED ON: TRANSPORTATION USAGE STUDY,
COOK COUNTY HIGHWAY DEPARTMENT

FIGURE 3



EXISTING "PULL"		% OF TOTAL "PULL"	NO. OF TRIPS	VEHICLE MILES
FROM C_1 = 100 X 4.0 = 400		57	456	456
FROM C_2 = 200 X 1.00 = 200		29	232	464
FROM C_3 = 400 X 0.25 = 100		14	112	448
TOTAL "PULL"	700	100%	800	1368 MILES

PULL AFTER EXPRESSWAY IS BUILT				
FROM C_1 = 100 X 4.00 = 400		40	320	320
FROM C_2 = 200 X 1.00 = 200		20	160	320
FROM C_3 = 400 X 1.00 = 400		40	320	1280
TOTAL "PULL"	1000	100%	800	1920 MILES

Consider for a moment an imaginary expressway that would enable residents to travel to C3 in half the time, or 10 minutes. From the calculations shown, 800 trips would be reoriented in the following manner: 320 to C1, 160 to C2 and 320 to C3 resulting in 558 more vehicle miles or about a 40 per cent increase.

Further, the expressway would accommodate 208 additional vehicles and would increase traffic by nearly 185 per cent.

Similar reorientation in traffic movement would be observed if another type of land use were established in the vicinity, for instance, a new shopping center.

Benefits

As in a conventional type interview of O-D study, a synthetic study of this type permits the analysis of several transportation alternatives. The use of a model allows greater flexibility and a better opportunity to evaluate these alternatives.

By studying the two alternatives in Baltimore, the role of mass transit transportation was clearly defined. This survey revealed that Baltimore transit services, no matter how extensive cannot be considered a substitute for highway improvements. Nor will they drastically reduce highway building requirements.

The application of the traffic model in Baltimore, has provided the planning staff with a clearer conception of the city's traffic problems and, further, has helped it to envision the effect that land use arrangements have on traffic patterns. Factually, any type of land use plan can be evaluated with such a model, and it is possible to investigate many transportation alternatives, and to decide on the one making most "transportation sense."

Traffic models have been used effectively in other cities, for example Washington, D. C. Mass Transit Study conducted by the National Capital Regional Planning Commission evaluated one land use plan and four alternative transportation plans. Each alternative plan was created with the objective of meeting the transportation requirements of the proposed land use plan. Each plan varied with the type of transit facilities and service to be provided, as well as with the numerous highway improvements to be incorporated. Traffic models like the one developed for Baltimore, were used to estimate expected patronage of various transit proposals, in addition to highway volumes. In a comparison, the estimates presented a picture of the advantages of each of the four alternatives. With this type of data, Washington is now deciding on its transportation program.

The city of New Haven recently completed a study based on another method of synthesis from land use factors. Conducted over a period of a few months, this study provided the city planners and traffic engineers with a method of determining the advantages of different interstate locations. Similar studies are under way now in Hartford and Boston. In Boston, they are undertaking about 1,000 interviews in order to help strengthen the model and to make it adaptable to any local conditions which they find necessary.

This type of approach—that of using a model with a limited amount of interviewing—makes a great deal of sense in that local information is obtained which strengthens the model. At the same time, it is possible to adjust it to local conditions. No doubt, with the improvement of traffic models, more will be done along these lines.

SUMMARY

For more comprehensive highway planning, traffic models offer a variety of advantages. The factors influencing traffic patterns are better understood as a result of their use, and a more sound factual basis is established from which to base conclusions. Mathematical models also permit a more thorough evaluation and testing of alternatives, which results in more realistic overall plans.

Traffic models hold much promise because of their economy. The relatively low cost, (Baltimore's model approximated $25,000) the limited staff necessary and the technically simple procedures which are involved undoubtedly will contribute to their increasing popularity.

The benefits accruing to professionals in experimenting with and using traffic models should urge us to improve applicable techniques. When this is done, and a more effective mathematical traffic model is the outcome, urban highway planning will be more exacting.

As engineers, we have the responsibility of expediting improvements to the traffic model, for in the years ahead, it will be extremely valuable for the entire profession.

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Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

PUBLIC SERVICES ON CONTROLLED ACCESS HIGHWAYS

C. W. Hartford[1]

ABSTRACT

The article relates the services to the public on controlled access highways to urban, rural and toll road projects and divides the services discussed into services of necessity and services of convenience.

To properly determine the need of services for the traveling public on controlled access highways it is necessary to distinguish between the various types of controlled access highways and delineate between services of necessity and services of convenience.

Basically, there are three types of controlled access highways. First, there is the urban type improvement usually not too long with frequent interchanges and used principally by commuter or local traffic. These highways are, or will be, bounded by urban development and present familiar landmarks for orientation.

Next, there are the rural controlled access highways with infrequent interchanges, a lower density of traffic located in sparsely habited areas and used by a substantially greater percentage of strangers. Because there will be a paucity of familiar landmarks the motorist is faced with a very real problem in orientation, especially if he has need for service. The bulk of highways in this classification are those planned under the interstate program.

The third type of highway is closely related to the second but operated by an authority required to collect tolls to amortize the cost of construction. Most toll road authorities deemed it advisable to furnish package transportation for the motorist and provide for all his desires except overnight lodging. Even now at least one authority is planning to provide for that service and the Ohio Turnpike Commission furnishes aid to its patrons in locating accommodations. True, a toll road authority is interested in revenues and many of the services provide a substantial return.

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1. Executive Director, Ohio Turnpike Comm., Berea, Ohio.

Services of necessity are required on all three types of highway and include:

1. Disabled Vehicle Service
2. Police Protection
3. Fire Protection and
4. Ambulance Service

It will be noted these services are those usually brought to the motorist in need of services.

Because the urban projects are located in and around large cities and are well policed and the police are equipped with radio communications and can call these services through central headquarters there should be no problem in providing services of necessity.

Unlike the cities where reputable garages will provide disabled vehicle service there is apt to be the gypsy-type operator patrolling the rural highways in search of motorists in distress. Being uncontrolled by the necessity to maintain a reputation and unbounded by ethics some will charge in accordance with the seriousness of the situation rather than the service performed. The potentialities of this type operation are immense. There were approximately 29,000 services performed by the disabled vehicle contractors on the Ohio Turnpike during 1958 or an average of 120 services per mile per year.

Police protection on the rural interstate highways should, in most instances, be better than provided on the general system of rural highways but it is questionable if it can be adequate. Because there are no roadside services planned on the interstate system, no toll plazas and no disabled vehicle contractors on call by radio, the police will be the major source of communication with the outside world and their burden will be substantially greater than on any other type of highway. It may take a great deal of time and effort on the part of the policing authority to prove this point and gain approval of the appropriating authority of funds sufficient to provide adequate policing.

Local authorities, at least in Ohio, are required to provide fire protection within their jurisdiction. Fifty-seven different authorities have jurisdiction throughout the length of the 241-mile Ohio Turnpike. This is an average of 4.2 miles per jurisdiction. Because interchanges on the rural interstate system could not conceivably be spaced to accommodate fire districts, many districts will be required to travel through other districts to reach an interchange so they may service that part of the highway in their jurisdiction. Nothing could be less workable and less effective. Although fires are not a major problem in numbers of incidents they are a serious problem when they occur.

Ambulance service on the rural interstate highways should be no less satisfactory than the service provided on the usual rural highways except with respect to a problem in communications. This service is provided generally by operators in the larger communities and it is assumed that roads leading to these larger communities will be connected by interchange to the interstate highway.

Arrangements for services of necessity have been made by toll road authorities and because these arrangements differ in some respects with each authority the following remarks relate to the Ohio Turnpike only.

Disabled vehicle services on the Ohio Turnpike are provided, by contract, with independent operators. The contract includes stipulations with respect to equipment that must be furnished, prices which may be charged and

services that must be performed. The Commission equips the contractors' service truck with two-way radio on its operational frequency and the service truck operator is required to respond to a service call in not to exceed 30 minutes. The Commission receives no remuneration from these contracts.

Policing on the Ohio Turnpike is performed by the Ohio State Highway Patrol through a contract with the Commission. The Commission furnishes the police patrol cars and reimburses the State Highway Patrol its costs in operation.

In addition to duties of enforcement the patrolmen are a valuable asset in furnishing aids to motorists. They provide aid to motorists at the rate of approximately 1,000 times per month.

Currently the complement serving the Ohio Turnpike consists of 65 men including officers, five radio operators and one plainclothes man. After more than 4 years operation it has been deemed necessary to augment this force and 15 additional patrolmen will be added soon.

As previously stated the Ohio Turnpike passes through fire jurisdictions of 57 different authorities and these authorities are required to furnish service on the Ohio Turnpike in the same manner they provide service in any other area of their authority. In addition to access at the interchanges fire companies are permitted access at the rear gates of all service plazas and maintenance buildings. Even so, the Ohio Turnpike Commission deemed it advisable to supplement these services with equipment at the 8 maintenance buildings. Experience has reversed this plan so that now the local authorities supplement the Commission's services. During 1958 there were 167 fire calls on the Ohio Turnpike. Commission equipment answered all these calls and local authorities were summoned in 32 incidents.

Ambulance service on the Ohio Turnpike is furnished through agreements and contracts with funeral homes and others providing emergency ambulance service in the vicinity of the turnpike. Ambulance service for victims of accident and serious illness were required 250 times during 1958. The Commission pays for this service in most instances and the service has been excellent. Ambulances, like fire equipment are permitted access to the turnpike through the rear gates as well as the interchanges.

Next there is the problem of services of convenience. Found in this classification are:

1. Fuel
2. Food
3. Restrooms
4. Communications
5. Information

These are the services usually obtained by the motorist at locations providing the service as opposed to the services brought to him.

Because of frequent interchanges, proper orientation of the motorist, type of traffic and availability of these services in close proximity to the interchanges there is little of concern on the urban controlled access highway.

On the rural controlled access highway services of convenience might well become services of necessity. To illustrate this point there are service stations spaced approximately 30 miles apart on both eastbound and westbound roadways on the Ohio Turnpike yet an estimated 12,000 to 13,000 vehicles ran out of gas in 1958. This is a very small percentage of total traffic but a sizable number of motorists in distress. The disabled vehicle contractors served

6,700 out-of-gas incidents in 1958. The same motorists without roadside service would have no choice but to hitchhike to the nearest interchange in an effort to obtain fuel. His problem is greater if the next interchange is a connection with another limited access highway. Perhaps he would fare better if he awaited the "gypsy" previously mentioned.

Restrooms are placed under the classification of services of convenience. This classification will be questioned by many, especially a family traveling with young children. Even so, on a well-planned trip, stops are made at the convenience of the motorist. These same conclusions apply to food. The motorist will find these services when needed but only at the expense of additional distance and time. Public telephones and information are usually available at the same locations.

In this regard it must be remembered that the Ohio Turnpike is a link in a continuous controlled access highway extending from Chicago to New York, a distance of 837 miles. Other facilities joined in this 837 mile highway are the Calumet Skyway in Chicago, the Indiana Toll Road, Pennsylvania Turnpike and the New Jersey Turnpike. All of these toll roads, with the exception of the Calumet Skyway, provide services of convenience and the Ohio Turnpike Commission finds them well patronized. In an effort to determine the desires of the patron and the services used the Ohio Turnpike Commission in cooperation with the Ohio Department of Highways conducted a survey on certain selected days during December, 1956 and January, 1957.

With respect to fuel it was learned most motorists purchased fuel before entering the turnpike and the percentage buying gas on the turnpike is small and increases very gradually with length of trip up to 120 miles. Beyond 120 miles the increase is much more rapid. Practically all motorists stopped for gas on trips of approximately 240 miles.

In support of the conclusion that most motorists purchase fuel before entering the turnpike is the known fact that much more fuel is consumed on the turnpike than is purchased from the service stations on the turnpike. This finding is understandable when you know the average length of trip on the Ohio Turnpike is slightly more than 80 miles.

The findings from the survey with respect to food show that of all the motorists stopping at plazas for any reason, about 75% purchase food and on trips of 220 miles, 85% of the motorists stop at plazas for food as the primary reason for stopping. In comparing stops for food with stops for other purposes it can be shown that if frequent plazas were not provided the facility the motorist would miss most on trips up to 165 miles would be food. At about 165 miles the use of restrooms equals the use of food facilities. Although the use of restroom facilities on short trips is not great there is a consistent relationship with length of trip.

In planning for public telephones for the Ohio Turnpike the demand was grossly underestimated. Pay phones are available at each of the seventeen toll plazas and the sixteen restaurants. The greatest demand is at the service plazas and requires a continual increase in the number of telephones to supply the demand. On some busy week ends the telephones have been put out-of-order by coin boxes jammed beyond capacity.

As a source of information to the motorist the toll collectors are an invaluable asset. There is no limit to the variety of questions arising daily. To provide ready answers to many queries the Commission has published routings to destinations most frequently inquired about, directories of overnight accommodations within 5.5 miles of each interchange, travel tips and turnpike maps. These are all handed to motorists in response to questions relating to

the particular subject. This is definitely a service of convenience but it is believed the service is warranted because it saves the motorist time and miles and provides him comfort in his travels.

In summation it must be assumed that services of necessity will be provided on every controlled access highway leaving only efficiency of services a matter of concern. Time and experience should produce improvements in efficiency if such improvements are deemed necessary.

If services of convenience are not provided on the rural controlled access highway the motorist will suffer great inconvenience and expense in additional mileage required to find these services on the interconnecting highways. Loss of time in obtaining these services will nullify, at least in part, the advantage of time saving on a controlled access highway. Use of interchanges and traffic volumes on the interconnecting highways will be materially increased.

It is estimated that 6,725,000 customers were served in the restaurants on the Ohio Turnpike in 1958. Add to this the known fact that over 31,000,000 gallons of fuel were sold at the turnpike stations during the same period and you have a substantial volume of business which channeled to the interconnecting highways is bound to create a local problem of congestion.

It is difficult to state whether or not the demands of the traveling public using rural interstate highways will be similar to the demands made upon toll road authorities. All services in both categories are deemed necessary by toll road patrons and it is quite likely many travelers will expect the same services on the rural controlled access highways as well.

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REINFORCEMENT IN CONTINUOUS CONCRETE PAVEMENTS[a]

Closure by Vedat A. Yerlici

VEDAT A. YERLICI.[1]—The writer thanks Messrs. Zuk and Friberg for their interest in discussing his paper and agrees with them that "much more fundamental study," "thinking and discussion of the subject," "is necessary to resolve the present uncertainties about continuous pavements."

However, the writer cannot agree with all of the points raised and also wishes to clarify some of the misunderstandings.

1. "a" is not the "bond distance" as named by Mr. Zuk, but it is the length over which bond is broken. Eg. (2) includes this term "a" and the writer only points out that if "a" is assumed to be zero, then eg. (2) can be written as eg. (3). The use of eg. (3) to find the crack spacing "L" has not been suggested. Contrary to the belief expressed in the discussion, the writer in his conclusion recommends the use of eg. (2), not eg. (3), and uses it in his numerical example to determine "L".

2. The writer doubts Mr. Zuk's claim that only "peak bond stresses" "in the region of the cracks," "not an average stress based on a bar length," are important and that "much of the bar perhaps has no bond stress." Mechanism of cracking works such that, when the total bond force developed between the crack and a section of the concrete exceeds the ultimate tensile strength of concrete, a crack forms at that section. Therefore, the important question is "what is the total bond force developed along the length "L" of the steel bars?" It is not "what are the peak bond stresses?" When a minimum perimeter of reinforcement, "Σ_0" as given by eg. (11), is used, the total bond force exceeding the tensile strength of concrete at a section develops only along the full length "L". Then for this lower limit of the bar perimeter the total bond force can correctly be expressed as an average bond stress "μ" through length "L".

3. Mr. Friberg points out that "the numerical example of application of the computations is based on physical constants which are conventionally recognized as representative, except as regards shrinkage in concrete pavements and bond values in relation to the steel stress." The writer would like to make it clear that the numerical example is given to illustrate the method of design only and not to suggest any numerical values of the physical constants employed in the formulas. However, tests (Ref. 1, p. 33) of the writer and (Ref. 2, p. 28) indicate that a shrinkage value of 0.0002 in. per in. used in the numerical example is both a reasonable and conventionally recognized value. As far as the average bond stress of 300 psi. used in the numerical

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a. Proc. Paper 1799, October, 1958, by Vedat A. Yerlici.

1. Assistant Prof. of Civ. Eng. Robert College, Istanbul, Turkey.

example is concerned, it is believed to be quite a bit on the safe side and is generally recommended as an allowable unit bond stress for a 3000 psi. concrete by the 1956 ACI Code.

4. Mr. Friberg doubts "that shrinkage is a phenomenon of consequence in pavements." Yet internal capillary forces which attempt to contract the concrete always develop where initial moisture is lost by evaporation. In continuous pavements, where restraints against contraction are exceedingly high, tensile stresses develop under these forces. For complete restraint at the ends, a possible shrinkage strain of 0.0002 in. per in. and a tensile modulus of elasticity of 3,000,000 psi. a tensile stress of 600 psi. will tend to develop in the concrete. This is considerably higher than the ultimate tensile strengths of ordinary concretes. Therefore, it is believed that no matter how much the shrinkage strains and the tensile modulus of elasticity of concrete are minimized and the effect of tensile creep is considered the stresses developed by the tendency of shrinkage will remain to be an important cause of cracking.

5. As contradictory evidence to Mr. Friberg's thinking that "It is doubtful that steel stresses higher than 40,000 to 50,000 psi. could be expected in number 5 bars at 0.02 to 0.03 in. crack widths," the Report of the measurements made on the experimental pavements built in Pennsylvania can be stated.(3) There it has been reported that "between 40 and 56 days of age, the pavement steel reached such strains as to be in the yield range" and that "during the observations taken on the 40th day, the crack width varied between 0.0157 in. and 0.0190 in., while on the 56th day, the crack width variation fluctuated between 0.0142 in. and 0.0216 in." In these experimental pavements number 5 bars with an average yield point of 77,800 psi. were used.

6. The writer in no place mentioned or believed in "evenly distributed concrete tension stresses" nor in "evenly distributed bond stresses" as thought by Mr. Friberg. In fact eg. (1) uses an evenly varying tensile stress in concrete and eg. (10) uses an average bond stress whose distribution is not known.

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PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1859 is identified as 1859 (HY7) which indicates that the paper is contained in the seventh issue of the Journal of the Hydraulics Division during 1958.

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DECEMBER: 1859(HY7), 1860(IR4), 1861(IR4), 1862(IR4), 1863(SM5), 1864(SM5), 1865(ST8), 1866(ST8), 1867 (ST8), 1868(PP1), 1869(PP1), 1870(PP1), 1871(PP1), 1872(PP1), 1873(WW5), 1874(WW5), 1875(WW5), 1876 (WW5), 1877(CP2), 1878(ST8), 1879(ST8), 1880(HY7)[c], 1881(SM5)[c], 1882(ST8)[c], 1883(PP1)[c], 1884(WW5)[c], 1885(CP2)[c], 1886(PO6), 1887(PO6), 1888(PO6), 1889(PO6), 1890(HY7), 1891(PP1).

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JULY: 2079(HY7), 2080(HY7), 2081(HY7), 2082(HY7), 2083(HY7), 2084(HY7), 2085(HY7), 2086(SA4), 2087 (SA4), 2088(SA4), 2089(SA4), 2090(SA4), 2091(EM3), 2092(EM3), 2093(EM3), 2094(EM3), 2095(EM3), 2096 (EM3), 2097(HY7)[c], 2098(SA4)[c], 2099(EM3)[c], 2100(AT3), 2101(AT3), 2102(AT3), 2103(AT3), 2104(AT3), 2105(AT3), 2106(AT3), 2107(AT3), 2108(AT3), 2109(AT3), 2110(AT3), 2111(AT3), 2112(AT3), 2113(AT3), 2114(AT3), 2115(AT3), 2116(AT3), 2117(AT3), 2118(AT3), 2119(AT3), 2120(AT3), 2121(AT3), 2122(AT3), 2123(AT3), 2124(AT3), 2125(AT3).

AUGUST: 2126(HY8), 2127(HY8), 2128(HY8), 2129(HY8), 2130(PO4), 2131(PO4), 2132(PO4), 2133(PO4), 2134 (SM4), 2135(SM4), 2136(SM4), 2137(SM4), 2138(HY8)[c], 2139(PO4)[c] 2140(SM4)[c].

SEPTEMBER: 2141(CO2), 2142(CO2), 2143(CO2), 2144(HW3), 2145(HW3), 2146(HW3), 2147(HY9), 2148(HY9), 2149(HY9), 2150(HY9), 2151(IR3), 2152(ST7)[c], 2153(IR3), 2154(IR3), 2155(IR3), 2156(IR3), 2157(IR3), 2158 (IR3), 2159(IR3), 2160(IR3), 2161(SA5), 2162(SA5), 2163(ST7), 2164(ST7), 2165(SU1), 2166(SU1), 2167(WW3), 2168(WW3), 2169(WW3), 2170(WW3), 2171(WW3), 2172(WW3), 2173(WW3), 2174(WW3), 2175(WW3), 2176 (WW3), 2177(WW3), 2178(CO2)[c], 2179(IR3)[c], 2180(HW3)[c], 2181(SA5)[c], 2182(HY9)[c], 2183(SU1)[c], 2184 (WW3)[c], 2185(PP2)[c], 2186(ST7)[c], 2187(PP2), 2188(PP2).

OCTOBER: 2189(AT4), 2190(AT4), 2191(AT4), 2192(AT4), 2193(AT4), 2194(EM4), 2195(EM4), 2196(EM4), 2197(EM4), 2198(EM4), 2199(EM4), 2200(HY10), 2201(HY10), 2202(HY10), 2203(PL3), 2204(PL3), 2205 (PL3), 2206(PO5), 2207(PO5), 2208(PO5), 2209(PO5), 2210(SM5), 2211(SM5), 2212(SM5), 2213(SM5), 2214 (SM5), 2215(SM5), 2216(SM5), 2217(SM5), 2218(ST8), 2219(ST8), 2220(EM4), 2221(ST8), 2222(ST8), 2223 (ST8), 2224(HY10), 2225(HY10), 2226(PO5), 2227(PO5), 2228(PO5), 2229(ST8), 2230(EM4), 2231(EM4), 2232(AT4)[c], 2233(PL3)[c], 2234(EM4)[c], 2235(HY10)[c], 2236(SM5)[c], 2237(ST8)[c], 2238(PO5)[c], 2239(ST8), 2240 (PL3).

NOVEMBER: 2241(HY11), 2242(HY11), 2243(HY11), 2244(HY11), 2245(HY11), 2246(SA6), 2247(SA6), 2248 (SA6), 2249(SA6), 2250(SA6), 2251(SA6), 2252(SA6), 2253(SA6), 2254(SA6), 2255(SA6), 2256(ST9), 2257(ST9), 2258(ST9), 2259(ST9), 2260(HY11), 2261(ST9)[c], 2262(ST9), 2263(HY11), 2264(ST9), 2265(HY11), 2266(SA6), 2267(SA6), 2268(SA6), 2269(HY11)[c], 2270(ST9).

DECEMBER: 2271(HY12)[c], 2272(CP2), 2273(HW4), 2274(HW4), 2275(HW4), 2276(HW4), 2277(HW4), 2278 (HW4), 2279(HW4), 2280(HW4), 2281(IR4), 2282(IR4), 2283(IR4), 2284(IR4), 2285(PO6), 2286(PO6), 2287 (PO6), 2288(PO6), 2289(PO6), 2290(PO6), 2291(PO6), 2292(SM6), 2293(SM6), 2294(SM6), 2295(SM6), 2296 (SM6), 2297(WW4), 2298(WW4), 2299(WW4), 2300(WW4), 2301(WW4), 2302(WW4), 2303(WW4), 2304(HW4), 2305(ST10), 2306(CP2), 2307(CP2), 2308(ST10), 2309(CP2), 2310(HY12), 2311(HY12), 2312(PO6), 2313(PO6), 2314(ST10), 2315(HY12), 2316(HY12), 2317(HY12), 2318(WW4), 2319(SM6), 2320(SM6), 2321(ST10), 2322 (ST10), 2323(HW4)[c], 2324(CP2)[c], 2325(SM6)[c], 2326(WW4)[c], 2327(IR4)[c], 2328(PO6)[c], 2329(ST10)[c], 2330 (CP2).

c. Discussion of several papers, grouped by divisions.

HW4

DECEMBER 1959 — 47
VOLUME 85

NO. HW 4
PART 2

Your attention is invited

NEWS OF THE HIGHWAY DIVISION OF ASCE

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

JOURNAL OF THE HIGHWAY DIVISION
PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

DIVISION ACTIVITIES
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

NEWS

December, 1959

AN ANSWER TO CRITICISM
(An Editorial)

During hearings before the last session of Congress concerned with a continuance of Federal financing for the Interstate and Defense Highway System, it was alarming to note that charges were made to discredit the work accomplished to date in the construction of this highway system. These charges alleged that the Highway Engineers of the nation had resorted to extravagance in the location, design, and construction of this master system of nation-wide expressways. From the nature of the complaints it is apparent that the charges are being leveled by a small group of individuals who have little knowledge of the concept or the magnitude of the undertaking. However, the noise they create may result in serious setbacks for the program in future years unless their unrealistic statements are promptly corrected.

Highway engineers, in developing the concepts and establishing designs for this network of free expressways, employed three basic principles which can be described as safety, permanence, and service. To provide for the safety of public travel, adequate traffic lanes, wide median strips, flat curvature and minimum grades are incorporated in the geometric standards of design; for permanence, heavy foundations, high types of pavement and the use of durable materials have been specified for construction purposes; for service, the concept of providing new expressway facilities for the nation has required that large segments of the work be located within our most highly developed urban areas. The urban highway sections with adequate feeder or spur roads have, in many instances, been located to eliminate the blighted sections of metropolitan areas. Within the more rural areas, through careful planning a maximum of service is being provided to the smaller communities that fringe on this master network of highways.

Should Congress undertake an investigation of this program it will find that the highway engineers of the nation, working with all of the tools available to them, have conceived for the nation a master network of free expressways that will be so located and constructed as to provide safety, permanence and service for as far into the future as it is possible to foresee.

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To incorporate the above-noted features, initial costs will be high. However, a careful study will reveal that current costs are within previous estimates established by the engineers. It is predicted that once this great transportation system is understood by the public and usable segments of it are placed into operation, recognition will come to the highway engineer for his wisdom and vision in the development of this unique highway transportation facility. The system will be recognized for its safety and permanence. A system that by the very nature of the service it will provide, will materially chart the orderly development of the national economy as our population expands. The integrity of the program and the highway engineers of this nation should not be discredited by the unfounded statements of a small vociferous minority.

John O. Morton
Chairman, Executive Committee;
Commissioner, Department of
Public Works and Highways,
State of New Hampshire

* * * * *

THE WASHINGTON CONVENTION

The recent convention in Washington, D. C., during the week of October 19th, contained much that was of interest to highway engineers. The Highway Division presented four sessions: two in conjunction with the City Planning Division, a joint session with the Construction Division, and one sponsored by the Highway Division itself.

The first of these sessions dealt with the participation by the United States in highway construction abroad. Mr. Frank C. Turner, Deputy Commissioner and Chief Engineer, United States Bureau of Public Roads, described the type and quality of the technical assistance provided by the Bureau in foreign countries. He was followed by Mr. Robert O. Swain, Executive Director of the International Road Federation, who spoke of the general improvement in highway systems in most foreign countries. Mr. Lacey V. Murrow, President of Transportation Consultants, Inc., the final speaker at this session, discussed attitudes and methods of American engineers in foreign countries. "If we as American engineers," said Mr. Murrow, "are to accomplish our assigned missions and at the same time act as agents of good will for our country, we must continually bear in mind the highly sensitive feelings and attitudes of the peoples in the countries of assignment." Another point made by Mr. Murrow was that "American engineers can quite properly be accused of overdesign in some areas and countries." The use of A.A.S.H.O. standards in some countries, he went on, " . . . is commendable only if the engineer recognizes and differentiates between the numerous approved standards to which reference is made . . . . . standards for secondary roads are entirely adequate in many areas."

The second session, a joint Highway-City Planning program, dealt entirely with the Washington Area Transportation Study. Mr. Wilbur S. Smith of Wilbur S. Smith and Associates described the analysis and development of forecasts for future travel data in the metropolitan area. Mr. William

R. Mc Conochie, Chief of the Traffic and Transportation Section of De Leuw, Cather and Company, explained the procedure used in determining the best plan for the area. Four basic schemes were studied:

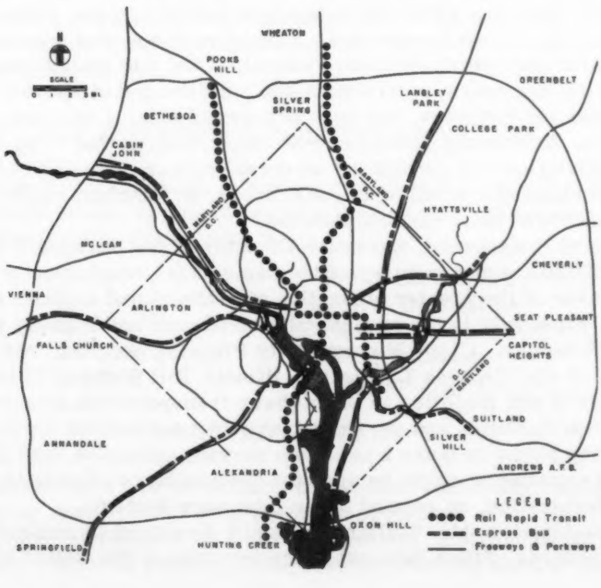
Plan I - the auto-dominant system. This would consist of an extensive network of freeways, parkways and arterial streets together with large-capacity downtown parking facilities. Public Transportation would consist of buses sharing the streets and highways with other automotive traffic as at present.

Plan II - the express bus system. This would comprise high-speed buses making few stops and traveling on freeways and parkways and maintaining a high standard of transit service. Local buses would supplement the express service.

Plan III - the rail or other train - type transit system. This would be on grade-separated ways located either in the center malls of radial freeways or on other exclusive rights-of-way, with trains providing fast service.

Plan IV - the information obtained from these three basic study plans was used to formulate a recommended transportation plan to facilitate the optimum movement of people and goods in the National Capital Region. This recommended plan is shown schematically below:

This exposition was followed by an appraisal, by Mr. Donald C. Hyde, General Manager of the Cleveland Transit System, of the transit facilities proposed for the Washington Metropolitan Area. Mr. Hyde believes "that the new concepts of transit proposed in the recommended plan will attract many thousands of persons who would otherwise drive autos. The diversion to transit in peak hours will relieve overcrowding on proposed new freeways and make them more useful to auto drivers. Increased travel by transit to the central area will check the flood of autos to the central area, thereby



minimizing traffic congestion on its local streets and substantially reducing the need for increased parking spaces which would otherwise be tremendous."

In describing the financing and administering of the proposed transportation system, Mr. Robert A. Keith, Project Director, Mass Transportation Survey, National Capital Planning Commission, explained that the total system cost will be approximately $2.5 billion, or a little more than $100 million per year for each year to 1980. The express transit facilities will cost about $ 564 million, or 20 percent of the total. The cost of downtown parking facilities is $119 million. Mr. Keith estimated that "the amount that would likely be spent under present Federal Aid programs and from other normal programs is $1.3 billion." An additional $500 million that is needed for highways, however, seems so difficult to raise "that there is no question but that the new $500 million must come from a new source of revenue." As to organization, "the Survey has recommended . . . . . a metropolitan transit agency, rather than a general transportation agency. The proposed agency would have the following duties and powers:

(a) To construct and own transit facilities;
(b) To operate transit facilities or to contract with private firms for their operation;
(c) To finance its operations from transit fares, by the use of limited tax powers and by other appropriate devices;
(d) To review highway construction plans as they may affect transit facilities, and to consult with highway agencies on these plans;
(e) To assist highway agencies in overcoming any deficit in funds; and
(f) To regulate and coordinate private firms engaged in public transit service."

The next session was in conjunction with the Construction Division, and featured a panel discussing "Problems and Trends in Highway Financing." Mr. Ellis L. Armstrong, Commissioner, United States Bureau of Public Roads, made the point that "the 1959 legislation will permit the new Federal-Aid program to continue without too serious a slow down," and that "the complex working relationship which involves Federal, State, and local highway officials, consulting engineers, contractors and builders and others who plan, design, and build our highways, has been preserved without too serious a strain." Commissioner Armstrong concluded with the statement that "I do feel sure that later legislation will reflect the universal role of motor vehicles in every phase of American life, whether in rural areas, in suburban communities, in our cities and towns or in national defense."

Mr. Bernard Hillenbrand, Executive Director of the National Association of County Officials, and a member of the same panel, emphatically stated his position in favor of the greater utilization of professional engineers in county government, especially in the implementation of road and highway programs.

The fourth session, a joint Highway-City Planning program, contained the observations of Mr. Charles L. Dearing, Illinois Toll Highway Commission, on (1) the role of toll facilities in the highway transportation economy, and the type of physical facilities and services that public authorities have provided to the motoring public to make a premium service attractive; and (2) the way in which this experience might be used for the avoidance of pitfalls in planning highway modernization, as related to the Interstate System.

At this session also, Mr. William R. Ewald, Assistant Commissioner for Technical Standards, Urban Renewal Administration of the United States

Housing and Home Finance Agency, commented that "the solution of urban traffic problems is not simply the handling of urban traffic as traffic problems only. Re-routing and handling of traffic can have an enormous impact on the urban property the artery cuts through or services. The effect of traffic 'solutions' on urban land use, economics, liveability or urban aesthetics is all of one bundle with the 'solution' of the traffic problem. Considering traffic as anything less is as impossible as a one-legged octopus."

COMMITTEE NEWS

Executive Committee

At the meeting of the Executive Committee in Washington on October 20th, the following changes were made in the make-up of the Executive Committee:

Commissioner John O. Morton, of the New Hampshire State Highway Department, is Chairman of the Committee.

Director William A. Bugge, Department of Highways, State of Washington, is now Vice Chairman.

Members of the Committee are Arch N. Carter, and J. Paul Buckley, former Secretary of the Committee.

Joining the Executive Committee as a new Member, and as Secretary, is Charles F. Mc Cormack, Deputy Chief Engineer with the Highways Division of the Automotive Safety Foundation.

Also at the Washington meeting of the Committee retiring member William A. Mc Williams, before leaving the meeting, said that he had "enjoyed my four years with the Committee. Call on me at any time to assist the Committee. It has been a rewarding experience."

The newly-constituted committee thereupon passes a resolution of appreciation of the services rendered by retiring member William A. Mc Williams.

Another resolution was passed in recognition of the services performed by retiring Secretary Buckley. Particular thanks were directed to his able assistants at the Automotive Safety Foundation: Mrs. Helen M. Tuttle and Miss Marian Hankerd.

NEW EXECUTIVE COMMITTEE SECRETARY

Mr. Charles F. Mc Cormack is now Secretary of the Executive Committee, and all communications, copies of correspondence, etc., previously addressed to J. P. Buckley should now be sent to:

C. F. Mc Cormack, Secretary
Executive Committee
Highway Division, ASCE
200 Ring Building
Washington 6, D. C.

NEW PERIODICAL

"Going Places" is a new bi-monthly publication containing reprints and new material on metropolitan transportation problems.

The magazine is published by General Electric. Address inquiries to "Going Places", General Electric Company, Locomotive and Car Equipment

Department, 2901 East Lake Road, Erie, Pennsylvania. It is free of charge to engineers and officials.

SOIL SCIENCE

This is a monthly magazine containing research papers on soil investigation, published under the editorial direction of the department of soils of Rutgers University. The magazine has been published since 1916 by the Williams and Wilkins Company, 428 East Preston Street, Baltimore 2, Maryland, at a subscription price of $10.00 per year.

PERTINENT PUBLICATIONS

Traffic Accident Studies - 1958 - Bulletin 208. Highway Research Board, National Research Council, 2101 Constitution Avenue, Washington, D. C., 83 pp. $1.60

This buletin contains the following six papers on various phases of traffic accident studies as presented at the 37th Annual Meeting of the Highway Research Board:

"Traffic Accidents and the Quality of Traffic Flow" - Bruce D. Greenshields

"Economic Costs of Motor Vehicle Accidents - Robie Dunman

"Statistical Evaluation of Traffic Accident Severity" - Edmun J. Cantilli

"An Analysis of One - Car Accidents" - R. W. Bletzacker and T. G. Brittenham

"Predicting Traffic Accidents From Roadway Elements on Urban Extensions of State Highways" - J. A. Head

"Sampling Procedures for Determining Speed Characteristics at Rural Locations: A Progress Report" - J. W. Guyton and A. K. Stonecipher

An Outline of Photogrammetry - K. Schwidefsky. Pitman Publishing Corporation, 2 West 45th Street, New York 36, N. Y., 1959. 326 pp. $13.00 (Available at the Engineering Societie's Library.)

Translated from the German, this text gives a presentation of the fundamentals, methods, instruments, and results of photogrammetry from a practical standpoint. While German instruments and methods predominate, an attempt is made to cover achievements in other countries also. Topics discussed are terrestrial photogrammetry, aerial photography, plotting serial photographs with simple equipment, rectification of single photography, stereophotogrammetry, and applications of photogrammetry.

Surveying - Fourth Edition - H. Bouchard and F. H. Moffitt. International Textbook Company, Scranton 15, Pennsylvania, 1959. 664 pp. $10.50 (Available at the Engineering Societie's Library.)

Together with the basic principles of surveying, this book provides sufficient information for working knowledge of special surveying topics such as

photogrammetry, and the use of accurate design topographic maps for determining earthwork quantities. The text has been brought up to date in this edition, with major changes in presentation.

Skid Conference Report - Virginia Council of Highway Investigation and Research Box 3817, University Station, Charlottesville, Virginia, 600 pp. 10.00.

This is the Proceedings of the First International Skid Prevention Conference. This 600 page publication is composed of two parts, containing 59 papers, with discussions. The areas covered are:

(a) kinds of skidding and accidents involving skidding;
(b) the human element in skidding;
(c) the relationship of tire design and composition to skidding;
(d) laboratory and field methods of measuring road surface friction;
(e) the relationship of road surface properties to skidding; and
(f) a comparison of several methods of measuring road surface friction.

Skid Prevention Research - 1959 - Bulletin 219. Highway Research Board, National Research Council, 2101 Constitution Avenue, Washington 25, D. C., 73 pp. 1.40.

This bulletin contains the final reports of several committees to the First International Skid Prevention Conference, held at University of Virginia in September 1958, together with other pertinent papers in the skid prevention field presented at the 38th Annual Meeting of the Highway Research Board. The following are included:

"Resume of First International Skid Prevention Conference" - Tilton E. Shelburne

"Accidents and the Human Element in Skidding" - Final Report of Subcommittee B.

"Relationship of Vehicle Dynamics to Skidding" - Final Report of Subcommittee.

"Relationship of Tire Design and Composition to Skidding" - Final Report of Subcommittee

"Relationship of Road Surface Properties to Skidding" - Final Report of Subcommittee D.

"Comparison of Several Methods of Measuring Road Surface Friction" - J. H. Dillard and T. M. Allen

"Review of Laboratory and Field Methods of Measuring Road Surface Friction" - Final Report of Subcommittee E.

"A Laboratory Investigation of Pavement Slipperiness" - J. W. Shupe and W. H. Goetz.

MEETING CALENDAR

ASCE MEETINGS - 1960

March 7-11	New Orleans Convention Contact: Louis Duclos Assistant Bridge Design Engineer State Department of Highways Baton Rouge, Louisiana
June 19-23	Reno Convention Contact: George Langsner Engineer of Design Division of Highways P. O. Box #1499 Sacramento 7, California
October 10-14	Boston Convention Contact: E. F. Copell Chief Engineer New England Division De Leuw, Cather & Company 361 Boyleston Street Brookline 46, Massachusetts

NON-ASCE MEETINGS - 1960

January 11-15	Highway Research Board Sheraton - Park Hotel Washington, D. C. Contact: Highway Research Board 2101 Constitution Avenue Washington 25, D. C.

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DEADLINE DATE FOR MARCH 1960 NEWSLETTER

January 15, 1960

Send contributions to the Newsletter Editor:

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